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SURFACE-WAVE AMPLITUDE-VERSUS-DISTANCE RELATION IN THE WESTERN UNITED STATES

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SEISMIC DATA LABORATORY

Under
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SURFACE-WAVE AMPLITUDE-VERSUS-DISTANCE RELATION IN THE WESTERN UNITED STATES

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ABSTRACT

For epicentral distances less than 15° in the Western United States, a new correction factor is proposed for use in the common Gutenberg formulation for surface-wave magnitude. The data on which this is based are 684 Rayleigh-wave amplitudes from Nevada Test Site explosions measured visually on the records of LRSM mobile stations and VELA observatories. The need for the variable T (period) in the magnitude calculation is discounted on empirical evidence. Magnitudes at distances less than 15° when recomputed using the new correction factor are in excellent agreement with teleseismic magnitudes and show less scatter among themselves than previously. An estimate of the effective Q_R in the crust from the data is about 130. Amplitude losses should reflect other causes than anelasticity, and this value is undoubtedly much lower than the real Q_R.

INTRODUCTION

The determination of seismic event magnitude has a prolonged history of debate and confusion. One part of the problem is to formulate or tabulate distance-correction vales which will, when applied to observed amplitudes, result in calculated magnitudes that are reasonably invariant among stations recording a particular event. In addition, there have been various proposals concerning what and where to actually measure on the record for magnitude determination. The proliferation of magnitude formulas is documented in the VESIAC Advisory Report (1964) and further by Båth (1966 and 1969). The generation of a large number of different formulas can mostly be explained by either differences in system response among seismographs around the world or by differences in regional structure for propagation paths studied. The first is of course artificial and could be eliminated; the second, however, could produce significantly different amplitude-versus-distance relations, both for body and surface waves, in different regions.

This report is concerned only with surface-wave magnitude, and is intended to serve as a complement to part of the work of Evernden (1967) which attacked the more difficult problem of determining at regional distances consistent body-wave magnitudes which were comparable to those computed at teleseismic locations. The formulation of a distance-correction factor has largely been an empirical effort in the past, and we will continue this approach while giving only a limited discussion of the theoretical causes of surface-wave amplitude diminution with distance.

The Seismic Data Laboratory has accumulated amplitude readings for surface waves from over fifty unclassified explosions at the

Nevada Test Site (hereafter referred to as NTS) and elsewhere. The advantage of using explosion data in this type of study is that azimuthally-dependent amplitude radiation patterns of earthquake source mechanisms will not contribute to scatter in the data. There is, of course, the possibility of tectonic release accompanying explosions as shown by Toksöz et al. (1965), but still the explosion data should be more suitable for this amplitude study.

THE SURFACE-WAVE MAGNITUDE FORMULA

The original Gutenberg surface-wave magnitude formula is:

$$M_G = \log_{10} A_\mu + 1.656 \log_{10}\Delta + 1.818 \qquad (1)$$

where A_μ is the sum of the maximum zero-to-peak horizontal amplitudes in microns of the Rayleigh wave measured at a period of about twenty seconds and Δ is measured in degrees (Gutenberg, 1945, equation (4)). Using maximum peak-to-peak amplitude instead, assuming a period of twenty seconds, converting to millimicrons, changing to measured vertical amplitude, Gutenberg's formula becomes:

$$M_G = \log_{10} (A_{m\mu}/T) + 1.66 \log_{10}\Delta - 0.18 \qquad (2)$$

which is the formula stated by Geotech (1964) and employed at the Seismic Data Laboratory continuously since 1964. Note that one must set T = 20 to return to (1); however, in practice T is measured at the maximum recorded amplitude and is variable in (2). Hereafter in this report the logarithmic base of 10 will not be written and is to be understood; also, the mμ subscript will be dropped and all amplitudes should be considered as measured in millimicrons. This report will speak of "Gutenberg magnitude" or "Gutenberg distance correction", and it is to be understood that (2) is implied rather than (1) even though (2) is not Gutenberg's exact formulation. The term "B factor" will also be used to indicate ($b \log\Delta + a$) so that (2) can be written as

$$M = \log (A/T) + B \qquad (3)$$

for the general case where $1.66 \log\Delta - 0.18$ is not necessarily implied as the correction factor.

It becomes apparent over a period of time, after individual station magnitudes calculated according to (2) for various NTS explosions were plotted versus distance, that magnitudes at regional distances were low relative to those at teleseismic distances. It was also noted that the periods of maximum motion were almost always between 10 and 16 seconds at less than teleseismic distances, and so the original requirement of Gutenberg that the measured amplitude be at a period of twenty seconds was seldom satisfied. The explanation for the low magnitudes was simply that Gutenberg did not use regional data in deriving his formula and did not intend it to be applied for magnitude determination at regional distances. Thus, the NTS data warranted formulation of a distance correction factor applicable to regional distances in the Western United States. The Gutenberg magnitude as given by (2) was assumed to be reliable for teleseismic distances since he based it on almost one thousand amplitude observations at distances greater than 13°, and a regional distance-correction factor was designed to force regional magnitudes to agree with those at teleseismic distance for the same events.

CORRECTION FACTOR FOR REGIONAL DISTANCES FROM NTS

As a data base we had available 704 Rayleigh-wave amplitude measurements from LRSM mobile stations and VELA observatories made visually at the Seismic Data Laboratory and elsewhere (see Bibliography of Shot Reports) for 47 NTS explosions through mid-1969. Rayleigh waves were recorded between 1.6° and 40° within continental North America. By preliminary analysis, twenty measurements were found to be either highly anomalous or in fact erroneous, and these were deleted from the data base. Figure 1 shows the geographical distribution of the remaining 684 Rayleigh-wave measurements. To illustrate effectively the relatively low magnitudes determined at regional distances by equation (2), the quantity $(M_{ij}-M_j)$ is plotted versus distance in Figure 2, where M_j is the average magnitude for the jth event as given by the average of the stations beyond 15° distance and M_{ij} is the magnitude given by the ith station for the jth event. If there were less than four stations beyond 15° for an event no M_j and thus no $(M_{ij}-M_j)$ were calculated for that event. Eighteen events comprising 103 of the 684 data points were eliminated by this criterion. Distances other than 15° were used, but the division at 15° proved best. This point in distance roughly coincides with the nominal division into "regional" and "teleseismic" distances, and mention of these terms in this report will imply the division at 15° distance. Figure 2 provides support for the assumption that Gutenberg's formula gives consistent magnitude values independent of distance in the teleseismic range.

Conclusive statistical proof of the inapplicability of Gutenberg's distance correction factor at less than 15° can be given by taking the 684 amplitudes and fitting by least squares

the constants a and b in the equation:

$$\log (A/T) = - (a + b \log\Delta)$$

for the two distance ranges 0° - 15° and 15° - 40° and again for the entire distance range. A method of testing whether both groups of data could possibly be fitted by the same straight line is given by Acton (1959, p. 81-82) and requires that only the standard deviations from the three lines be calculated. An F statistic was calculated from which it was concluded with greater than 99.9% confidence that the regional and teleseismic NTS data could not be fitted by each other's least-squares line. This implies that the amplitude-distance relation of regional observations is definitely different than that of the teleseismic observations.

In determining a regional distance-correction factor, the effect of the variable T in (2) should be examined; it is always less than twenty seconds for the maximum amplitude at these distances. The precise period of the cycle of maximum amplitude is usually difficult to assign at regional distances on continental structures since the wavetrain is dispersed very little; this is a source of error especially with LRSM and VELA data since the relative system response is rapidly decreasing at periods less than twenty seconds. Therefore, in this report two other amplitude measurements are considered, and distance-correction factors are determined appropriate to them. The first is simply A, the maximum recorded amplitude itself, divided by the system magnification at the period corresponding to the measured A value. The second will be designated $\hat{A}$ and is the maximum recorded amplitude divided by the system magnification at 25 seconds period, regardless of the actual observed period.

This $\hat{A}$, then, is the quantity least representative of true ground motion of the three proposed measures. However, even A/T and A are not necessarily maximum ground motions since the system response distorts the true spectral amplitudes of the signal. The amplitude measure for magnitude determination should not be judged on its physical basis but rather on the consistency of results obtained from it.

In determining a distance correction factor it would be advantageous to use all the data points available. This requires a normalization of the observed amplitudes, which represent explosions having a magnitude range of over two units, to reduce scatter of this dependent variable. Let us assume the form of the regional distance-correction factor to be the same as in Gutenberg's magnitude formula:

$$M = \log (A/T) + b \log\Delta + a \tag{4}$$

where a and b are constants to be determined. To determine the normalized value of amplitude, we write (4) for the jth event and ith station as

$$M_{ij} = \log (A/T)_{ij} + b \log\Delta_{ij} + a \tag{5}$$

and define

$$M_j = 1/N \sum_{i=1}^{N} M_{ij} = 1/N \sum_{i=1}^{N} [\log(A/T)_{ij} + b \log\Delta_{ij} + a] \tag{6}$$

using as the N stations only those at teleseismic distances where Gutenberg's magnitude formula is acceptable. If for some event there are less than four teleseismic stations, no M_j is computed and any regional observations for that event will

not be normalized and will be excluded from the least-squares determination of the regional distance-correction factor. This was the case for 18 of the original 47 events at NTS, leaving 330 points at $\Delta<15°$. So M_j is assumed to be the correct event magnitude, and values of the logarithm of the amplitude will be normalized to it. Using M_j rather than M_{ij}, (5) can be rewritten to effect this normalization:

$$\log (A/T)_{ij} - M_j = -(a + b \log\Delta_{ij}) \quad (7)$$

or

$$\log [(A/T)_{ij}/10^{M_j}] = -(a + b \log\Delta_{ij}) \quad (8)$$

This can be represented by the simple linear equation

$$y_k = -(a + bx_k) \quad (9)$$

where y_k is the logarithm of the normalized value of amplitude for observations at regional distances for all stations and all events. The least-squares solution for a and b will give the most consistent magnitude values at regional distances for an event and will simultaneously force the regional magnitudes to agree closely with teleseismic magnitudes determined by Gutenberg's formula for the same event. Another approach could have been to tie the regional distance correction factor to the Gutenberg one so that

$$a + bx_k = 1.66 \log\Delta - 0.18$$

at 15°, or

$$a + b \log 15° = 1.77.$$

Even though this would provide the pleasing result of making the distance-correction curve continuous, it is more important to seek the best least-squares solution of a and b and accept some discontinuity at 15°. Since Gutenberg's data extended from 15° to 130°, the correction factor determined by least-squares for this long range is not necessarily accurate at the 15° end point.

Least squares solutions of (9) were computed for the 330 points at $\Delta<15°$ using the three amplitude measures previously described so that y_k represented $\log [(A/T)_{ij}/10^{M_j}]$, $\log [A_{ij}/10^{M_j}]$, and $\log [\hat{A}_{ij}/10^{M_j}]$. The intercept a and slope b, the 95% confidence intervals on the slope and intercept assuming the other quantity as known, and the area of the 95% confidence ellipse on slope and intercept together are given in Table 1. However, the difference in area of the three confidence regions is not much, and the small degrees of improvement gained by using A or $\hat{A}$ are not really significant. The results show that $\hat{A}$, a quite simple measure, is as good as either A/T or A, which have more physical meaning. Use of $\hat{A}$ requires that the analyst only pick the largest amplitude on the record and divide by the magnification given at 25 seconds period, thus eliminating possible errors in reduction due to assigning a wrong period and due to additional mathematical operations when period is involved.

We will illustrate the improvement in regional surface-wave magnitude determinations when the revised "B" factor for regional distances is used in (3) rather than the Gutenberg "B" factor by plotting magnitude versus distance for several NTS explosions. First, the regional (hereafter called NTS) "B" factor and Gutenberg

"B" factor are plotted in Figure 3. Note that magnitudes determined at $\Delta=15°$ with the two different "B" factors would differ by 0.33 magnitude units. This we regard as a tolerable discontinuity in the "B" factor. Figures 4 through 17 show typically the improvement when the NTS "B" factor is applied at $\Delta<15°$ rather than the Gutenberg "B" factor. Not only is scatter somewhat reduced, but regional magnitudes become compatible with teleseismic magnitudes. This latter result is very important when magnitudes of small and large events are determined because the smaller events are naturally recorded at only shorter distances, and it is desirable that these regional recordings give a magnitude value equal to that which would result had stations at teleseismic distances been able to record the event. A histogram in Figure 18 has been prepared to show the reduction in standard deviations of surface-wave magnitude as determined from all recordings for those events having at least two LR observations. Evidently the use of the NTS revised "B" factor at less than 15° produces a better magnitude estimate for an event than the use of the Gutenberg "B" factor at these distances. Also, in Figure 19 the markedly better consistency of surface-wave magnitudes for the 41 events compared to the body-wave magnitudes for these same events using Evernden's (1967) corrections is evident. Surface-waves at regional distances are then definitely more predictable than body waves.

We can investiage whether the "B" factor for NTS events is dependent upon travel path by restricting amplitude observations to certain azimuths. The number of observations in the two sectors of 340°-20° and 110°-130° epicenter-station azimuth are sufficient to provide reasonable confidence limits on a and b when solving (8) by least squares (using A rather than A/T). We term these two sectors the "N" and the "ESE" profiles, and along

them there were 57 and 74 observations, respectively. Figure 20 shows the results at the 95% confidence level where the joint confidence ellipses on a and b overlap somewhat. Also shown is the 95% confidence ellipse for a and b using all the 330 observations. We can state with a fairly high degree of confidence that the rate of diminution of amplitude along the N profile is greater than along the ESE profile. Furthermore, there is reason to believe, although with somewhat less confidence, that diminution of amplitude throughout the rest of the Western United States is greater than along either of these profiles since the result for all observations is weighted heavily (60%) by observations outside these profiles. These differences in diminution rates can be attributed to regional tectonic nature, and this will be discussed later. However, "B" factors determined for the two profiles and for the entire group are not more than .11 magnitude units apart at any distance from 1° to 15°, and so for practical application in the Western United States, the NTS "B" factor determined from the entire group of data would be sufficiently accurate even along the N and ESE profile.

To test the applicability of the NTS "B" factor for events located elsewhere in the Western United States, Figures 21 and 22 were prepared in the manner of Figures 4 through 17 for two recent shots, RULISON and GASBUGGY, respectively. RULISON was detonated near Rifle, Colorado,[1] and the data was taken from preliminary analysis at the Seismic Data Laboratory. Magnitude data for the GASBUGGY event, near Farmington, New Mexico, was taken from Rasmussen and Lande (1968). Figure 21 shows that definite improvement is made by use of the NTS "B" factor for the RULISON event even though it is about 700 kilometers to the east of the Nevada Test Site and in a different tectonic region.

The GASBUGGY event, Figure 22, reveals some improvement with the use of the NTS "B" factor, but regional magnitudes are now overestimated relative to teleseismic ones; however, the teleseismic magnitudes for this event are few and are very scattered so that the average teleseismic magnitude has quite wide 90% confidence limits of ± 0.25 magnitude units. There were no United States explosions outside of the Western United States on which to test the NTS "B" factor mainly because of insufficient teleseismic recordings.

Q FOR THE PERIODS 10-16 SECONDS

The diminution of surface-wave amplitude with increasing epicentral distance can be wholly attributed to these causes: 1) geometrical spreading, 2) defocusing, 3) dispersion, 4) absorption, and 5) various reflection, scattering, energy conversion, and acoustic amplification processes inherent wave propagation through an inhomogeneous medium with non-parallel layering. Of these causes, only the first, geometrical spreading, is uniform and invariant over the earth. Harkrider (1964, equation (85)) shows that the distance-dependence of the vertical Rayleigh-wave displacement from an explosive source at the surface of a multilayered media is expressed by the zero-order Hankel function of the second kind [$H_0^{(2)}$ $(k_R r)$] where k_R is the wavenumber and r the epicentral distance. Whenever $k_R r$ is greater than about unity, this function can be closely approximated by $r^{-1/2}$ times a constant, and so cylindrical-wave spreading closely approximates the Rayleigh-wave spreading at distances as close as 100 kilometers. The sphericity correction for Rayleigh waves out to 15° is negligible. Thus considering geometrical spreading only, amplitude will be approximately proportional to $\Delta^{-1/2}$ for the distance range of this study. The second cause of amplitude diminution, defocusing as discussed by McGarr (1969), can probably be disregarded in this study because the extensive coverage over the Western United States of the data used would tend to average out defocusing effects with similar focusing effects.

To study the effect of dispersion on the amplitude-distance relation, several phase-velocity dispersion curves were selected from the collection of Brune (1969) and extrapolated if necessary; and Rayleigh-wave signals comprising the period range 5-100 seconds were synthesized in the manner presented by Sato (1960) at

distance increments of 200 km out to 1600 km using as a presumed source spectra the Fourier amplitude spectra of the CORDUROY event recorded at KN-UT, an epicentral distance of about 300 kilometers. A time window of the KN-UT record corresponding to Rayleigh-wave group velocities of 4.1 and 2.8 kilometers per second was used in the Fourier transformation; the end points of the time window are not critical since the maximum recorded amplitude occurs at some intermediate group velocity. The results of peak-to-peak maximum amplitude measurements on the synthesized signals for four different crust and upper-mantle structures is presented in Figure 23 using Brune's terminology. The log-linear plot shows that the data follows a relation of the form $A=\beta e^{-\gamma r}$. The value of the exponent can be determined only crudely since the data used in this study crosses several varying tectonic regions. We select though a value of the exponent which is midway representative of the "Basin-range" and the "Mid-continent" structures, and this is about -0.00018r.

We can now correct our 330 regional time-domain amplitudes for known geometrical spreading and dispersion effects by the relation

$$A'_{ij} = A_{ij}\ \Delta_{ij}^{1/2}\ e^{.020\Delta_{ij}}$$

where A'_{ij} is the corrected amplitude corresponding to the observed amplitude A_{ij} at station i for event j. These corrected values can be normalized to average teleseismic event magnitude M_j as done previously and then used in the common equation for attenuation,

$$[A'_{ij}/10^{M_j}] = A_o e^{-\alpha\Delta}$$

to estimate by least squares the absorption coefficient α over the Western United States. The value of α was found to be .067 $(\text{degrees})^{-1}$ with 95% confidence limits of $\pm$ .024, and since almost all of the amplitudes used in this fit were picked at periods of 10 to 16 seconds, this value will apply only to this limited band. In more familiar units, α = .00060 km^{-1} and the quality factor Q_R follows from the relation

$$Q_R = \pi/\alpha UT$$

where U is the group velocity. For our data $Q_R \approx 134$ with 95% confidence bounds of 98 and 208. This is to be regarded as an "effective" Q_R since we have not separated out the true absorption effect from other causes of amplitude diminution such as reflection, scattering, and mode conversion of Rayleigh energy in the Western United States. The complex topographic and tectonic character of the area covered by the data suggests that these latter phenomena may significatnly lower the effective Q_R.

CONCLUSIONS

Using 330 measurements of surface-wave amplitude at regional distances along with teleseismic measurements, a "B" factor for the Gutenberg magnitude formula has been determined which is applicable to the Western United States At less than 15°, the relation is

$$M = \log(A/T) + 1.16 \log\Delta + 0.74.$$

Values of M determined at $\Delta<15°$ by using A or $\hat{A}$ show somewhat less variance, and use of these measures is preferable in practice since reduction to ground motion from the film record involves fewer steps and removes a variable from the magnitude determination.

The differences in attenuation along particular paths around NTS is insignificant in regard to magnitude values, and the data used does not warrant determination of path-dependent "B" factors in the Western Unites States.

The effective Q_R (134) in the Western United States is quite low for the 10-16 second period range. Since the Rayleigh waves for these periods are primarily contained in the crust, this value is representative of the crustal layers, and as such is lower than that from the MM8 model of Anderson et al. (1965) or the "high-frequency" model of Tsai and Aki (1969). It must be pointed out though that these models were not constructed using data with periods as short as used in this report. However, a value of $Q_\beta \approx 450$ for shear waves in the crust was determined by Press (1964) using the L_g phase from NTS explosions. Further, a value of $Q_\alpha \approx 1000$ for compressional

waves in the crust was determined by Archambeau et al. (1969) using the P_n phase from explosions in Nevada. Since theoretically (Anderson et al., 1965) Q_R should be about 5% greater than Q_β and about one-half Q_α, our value of $Q_R = 134$ indicates definitely that diminution of Rayleigh-wave amplitude in the Western United States is due to causes other than anelasticity if we assume that LR waves are sampling much the same material as these body-wave phases and that Q is independent of period over the interval of one to sixteen seconds.

The difference in attenuation rates along the N and ESE profiles from NTS suggests that the effective Q_R is path-dependent in the Western United States. Whether this represents real changes in the anelasticity with region or other contributing factors to amplitude diminution is a formidable problem requiring more sophisticated analysis than undertaken here.

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BIBLIOGRAPHY OF SHOT REPORTS

The following abbreviations are used:

SDL - Seismic Data Laboratory, Alexandria, Virginia

Geotech - Geotechnical Corporation, Garland, Texas

AFTAC - Air Force Technical Applications Center, Washington, D.C.

SHOT	SDL No.
AUK	134
BENHAM	SDL preliminary analysis
BILBY	87
BOURBON	186
BOXCAR	223
BRONZE	132
BUFF	143
CHARCOAL	138
CHARTREUSE	156
COMMODORE	193
CORDUROY	Geotech No. 66-43
CUP	136
DES MOINES	SDL preliminary report
DILUTED WATER	128
DUMONT	160
DURYEA	153
FAULTLESS	215
FISHER	AFTAC Report
FORE	Geotech No. 64-34
GREELEY	180

SHOT	SDL No.
HARDHAT	AFTAC report
HAYMAKER	Geotech No. 63-4
HALF BEAK	171
KLICKETAT	131
KNICKERBOCKER	208
MADISON	SDL preliminary report
MARSHMALLOW	SDL preliminary report
MERRIMAC	38
MINK	SDL preliminary report
MISSISSIPPI	AFTAC report
NASH	184
PLANQUIN	144
PAMPAS	SDL preliminary report
PAR	135
PILEDRIVER	165
PIN STRIPE	154
RED HOT	145
REX	152
SCOTCH	200
SCROLL	220
SEDAN	36
SMALL BOY	37
STUTZ	Geotech No. 66-57
TAN	169
TURF	130
WAGTAIL	122
WISHBONE	129

TABLE 1

Least-Squares Solutions for Distance-Correction Factors

Amplitude Measure	Slope (b)	95% Confidence Limits	Intercept (a)	95% Confidence Limits	Area of 95% Confidence Ellipse
A/T	1.16	$\pm .05$	0.74	$\pm .03$	.0150
A	1.09	$\pm .04$	-0.34	$\pm .03$	.0123
$\hat{A}$	0.92	$\pm .04$	0.16	$\pm .03$	.0132

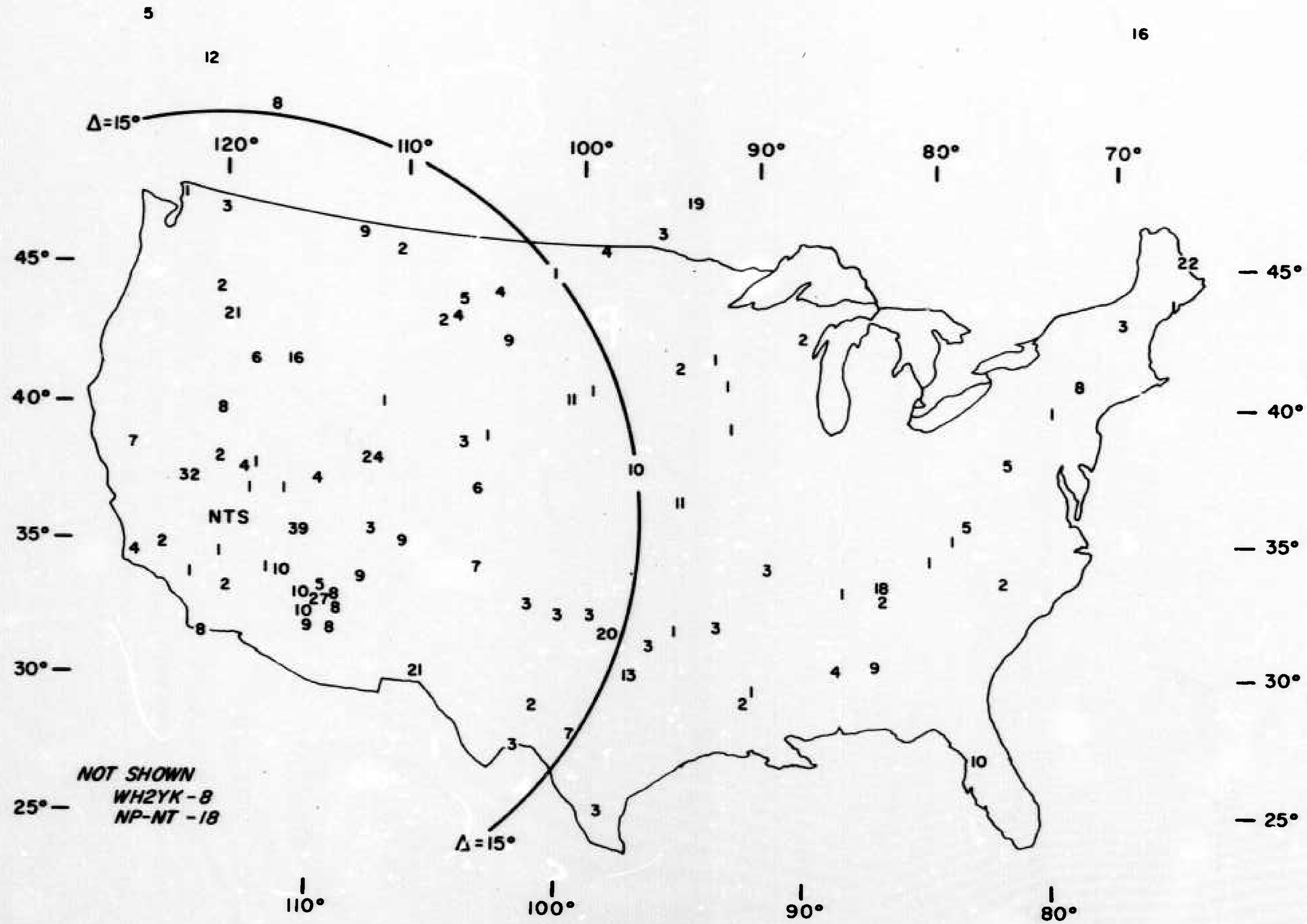

Figure 1. Geographical distribution of Rayleigh-wave amplitude measurements.

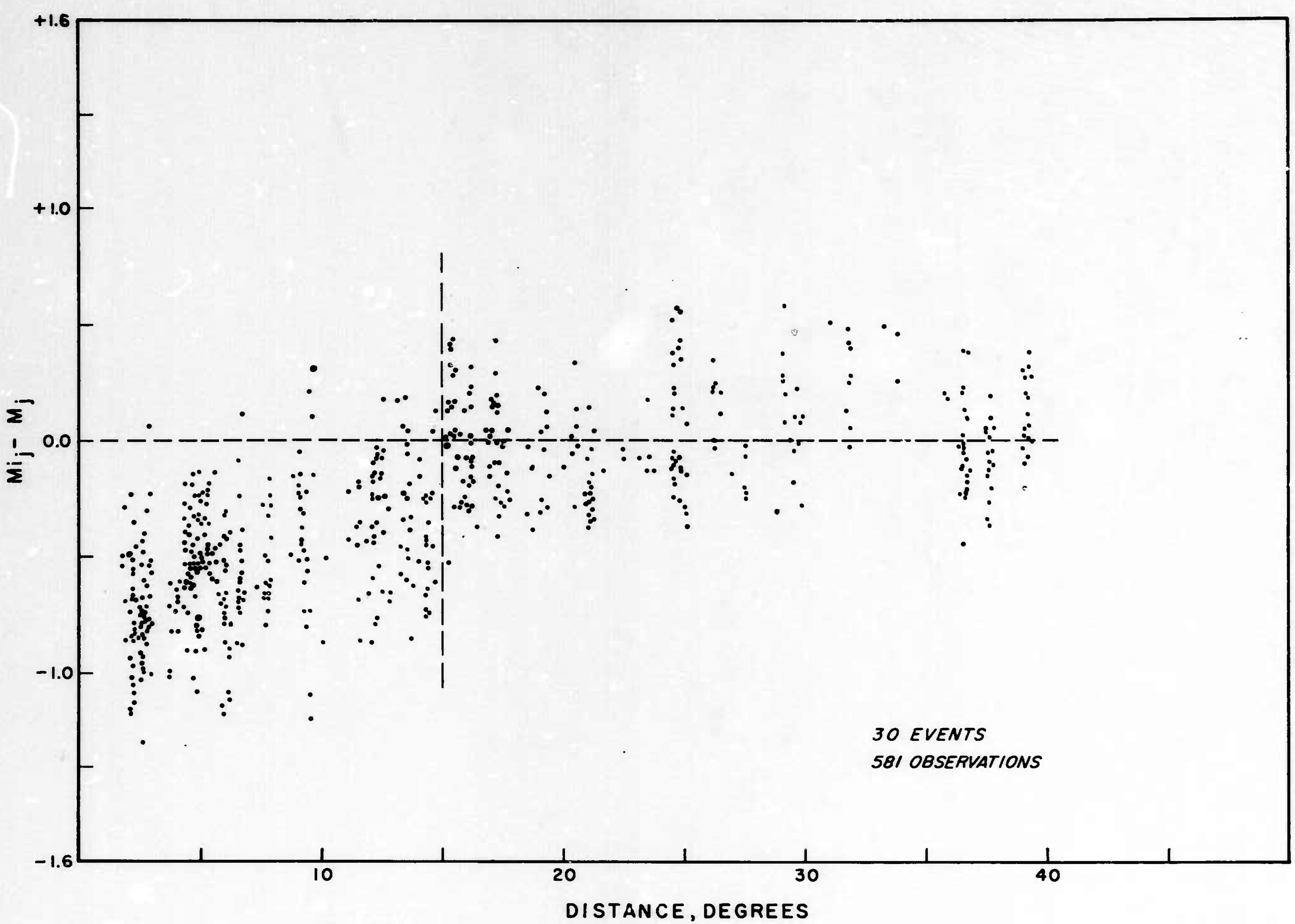

Figure 2. Individual magnitude deviations from the average for 31 Nevada Test Site explosions.

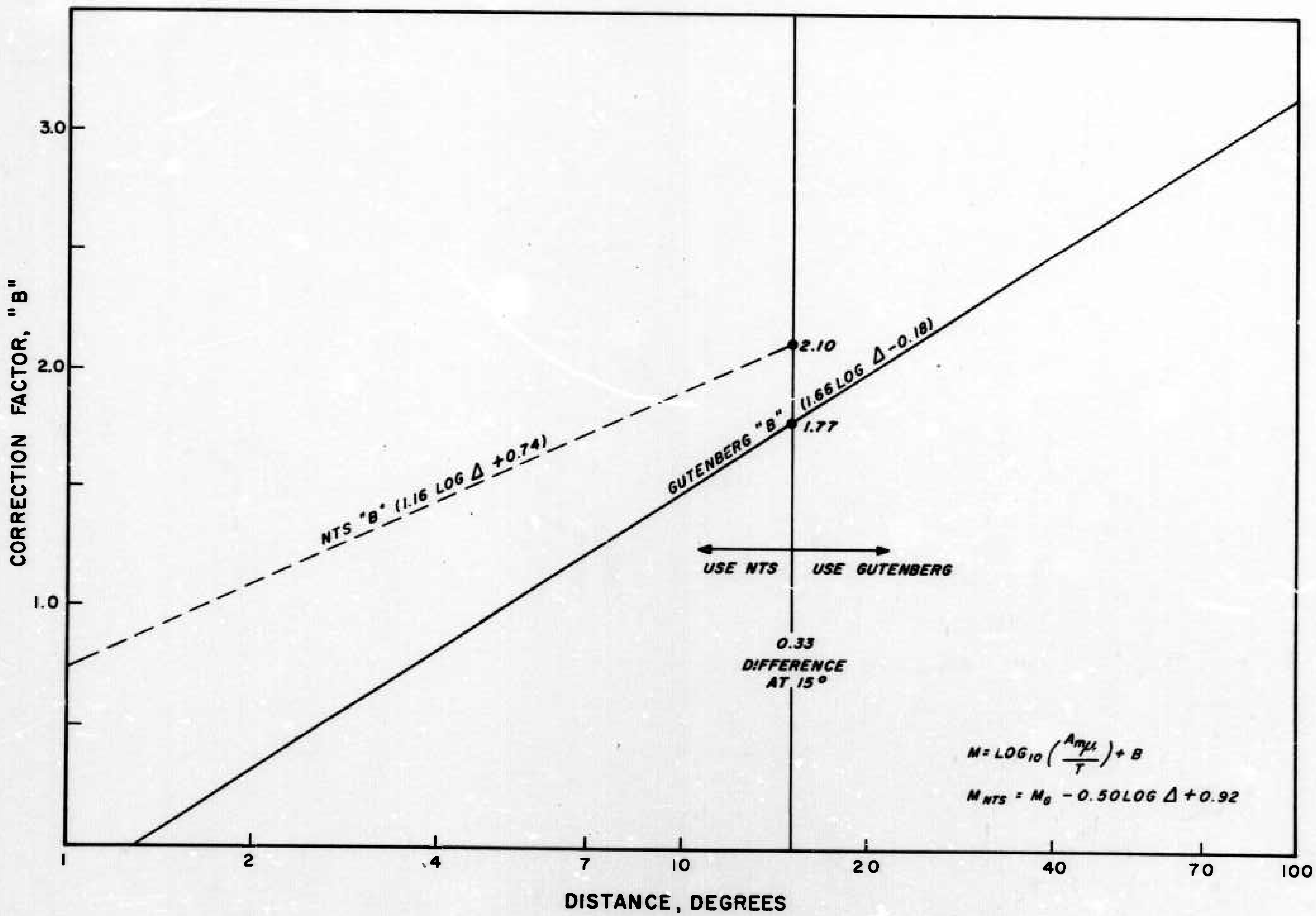

Figure 3. Gutenberg and NTS "B" factors.

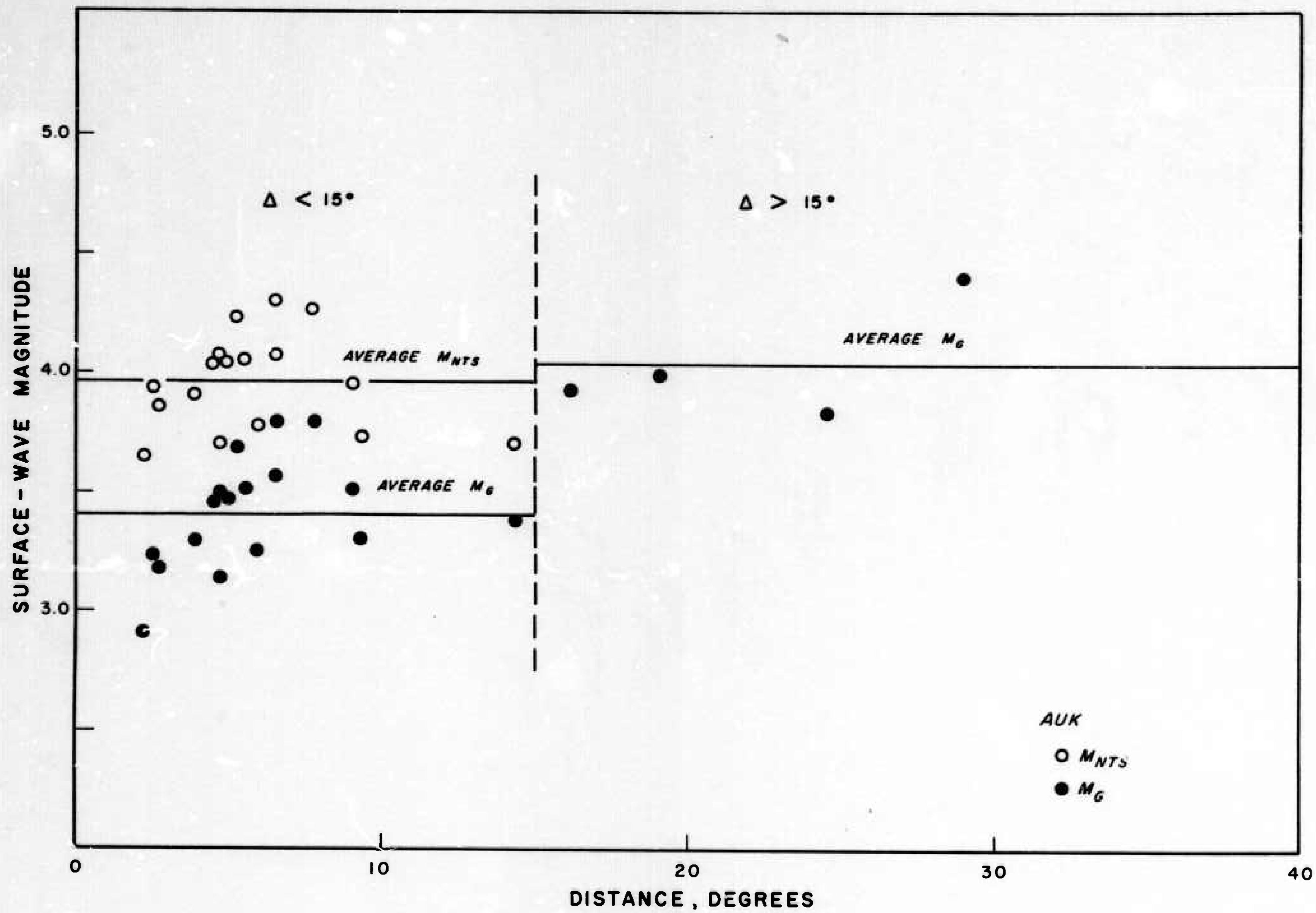

Figure 4. AUK - M_G and M_{NTS}

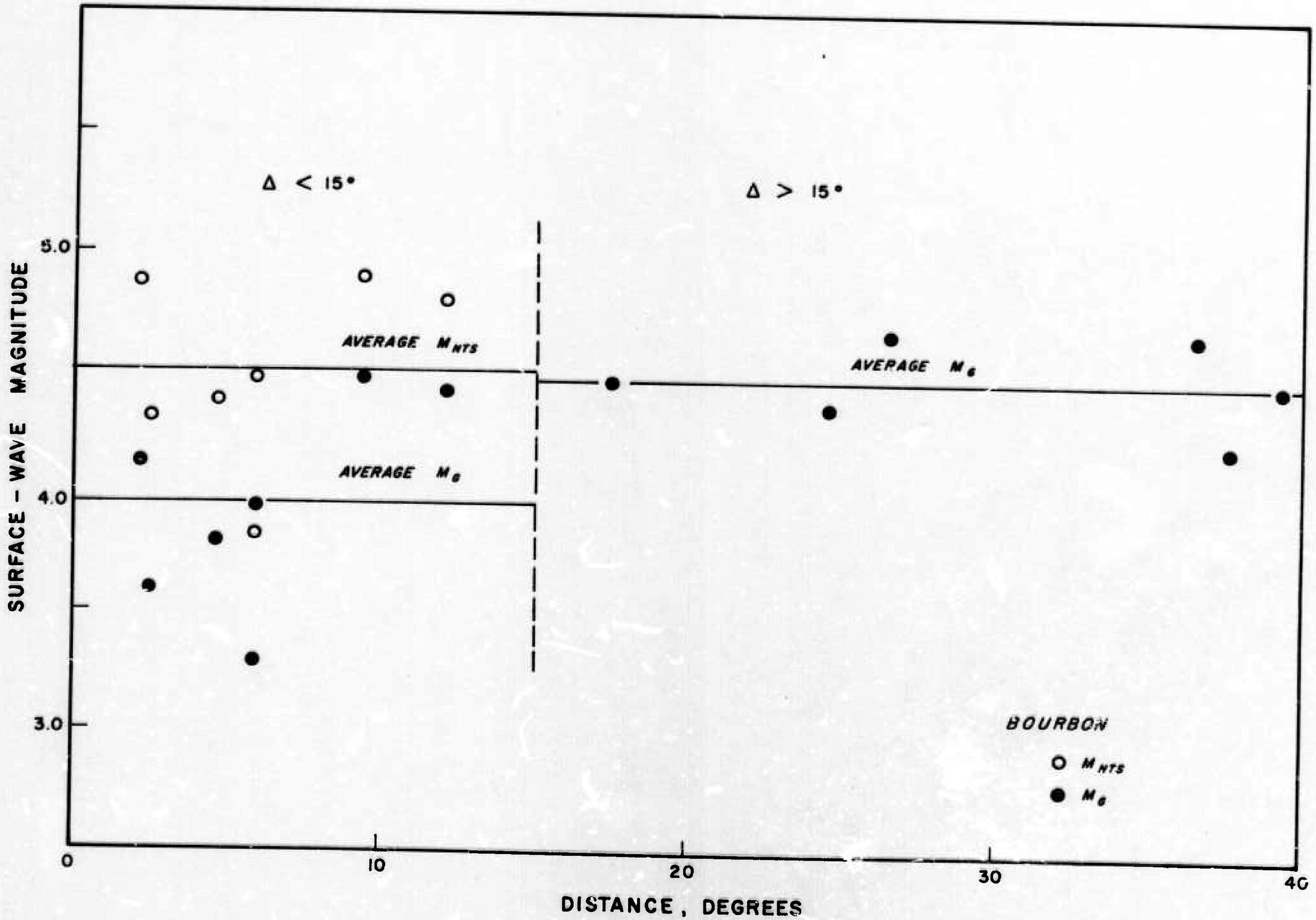

Figure 5. BOURBON - M_G and M_{NTS}

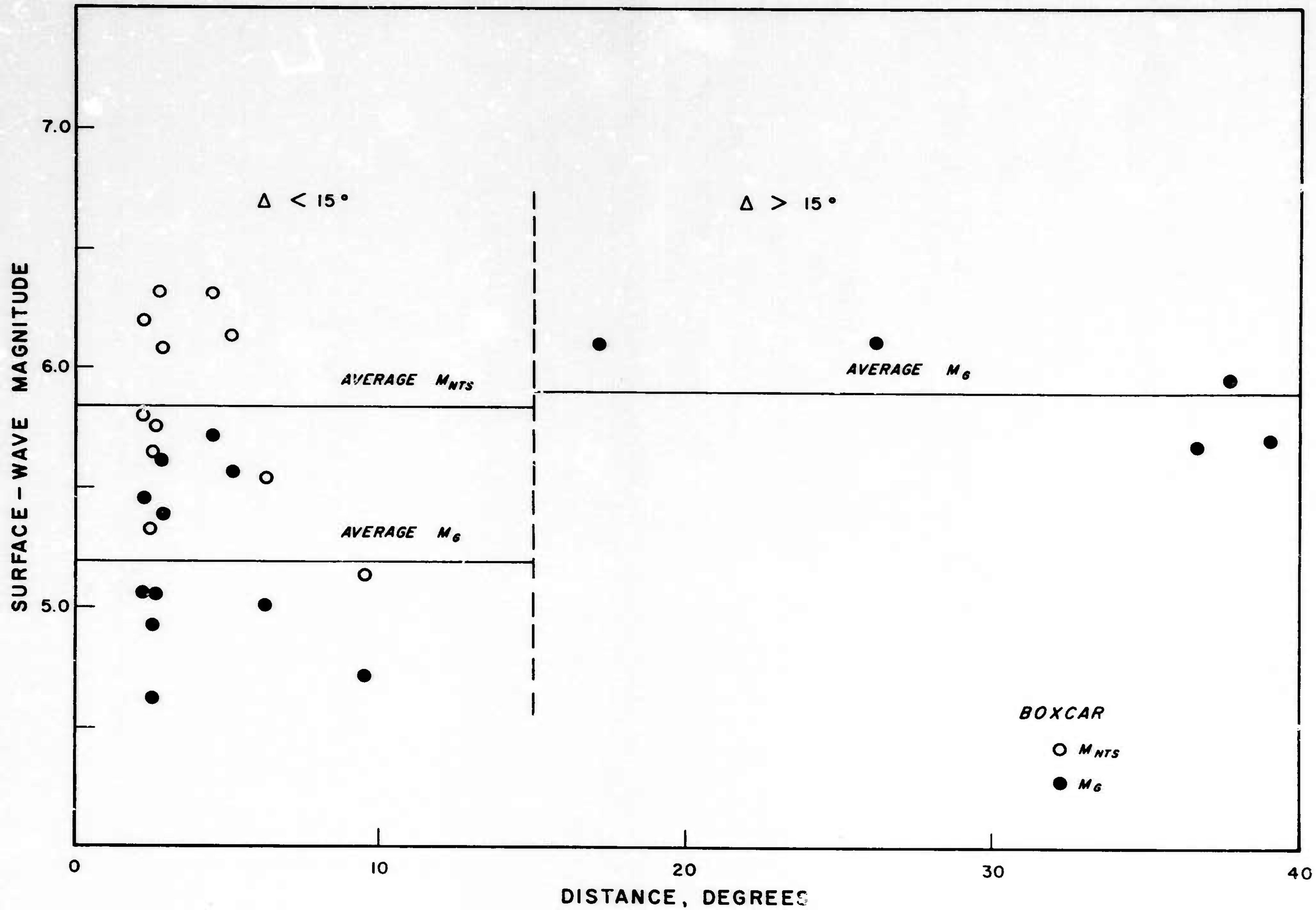

Figure 6. BOXCAR - M_G and M_{NTS}

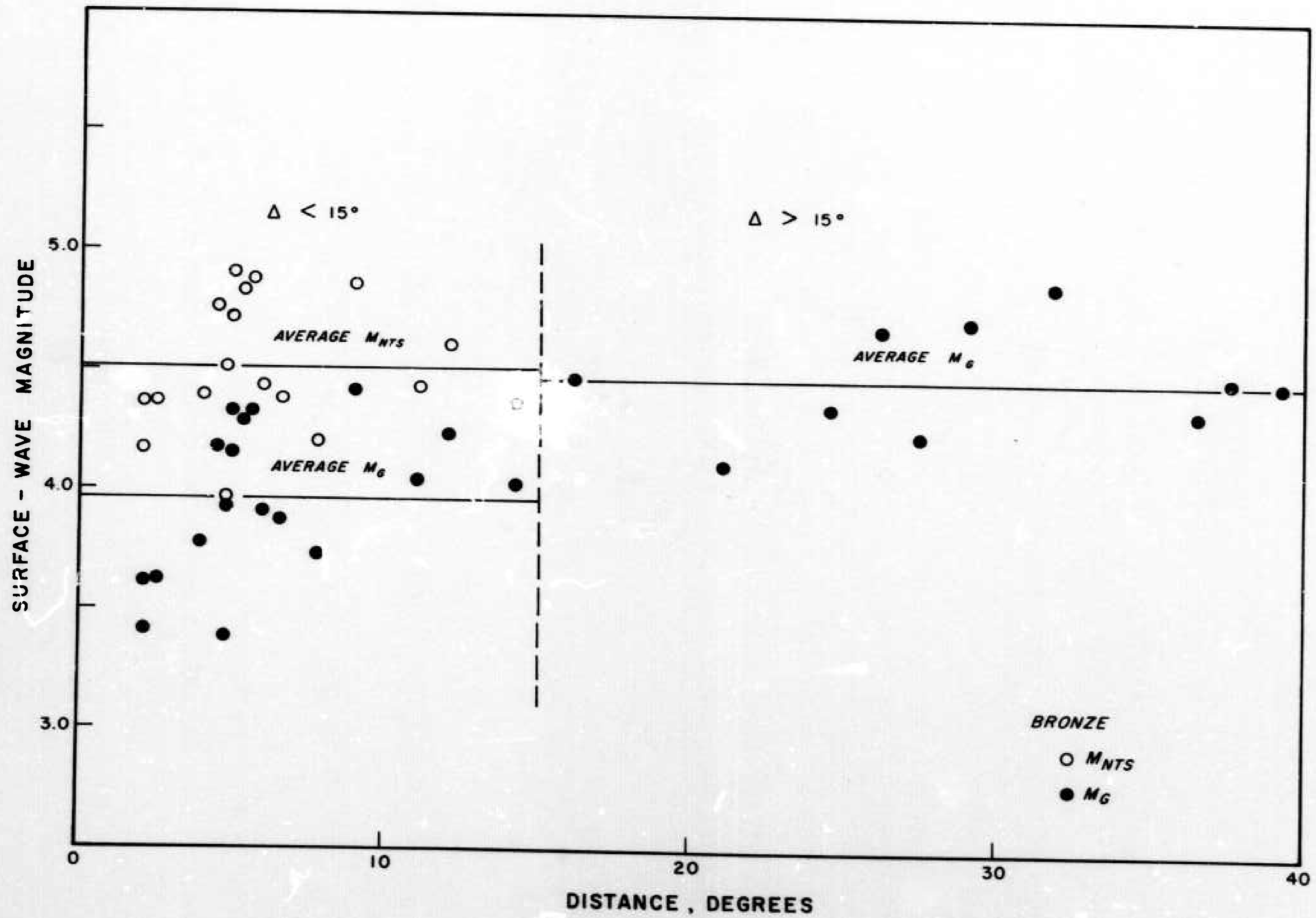

Figure 7. BRONZE - M_G and M_{NTS}

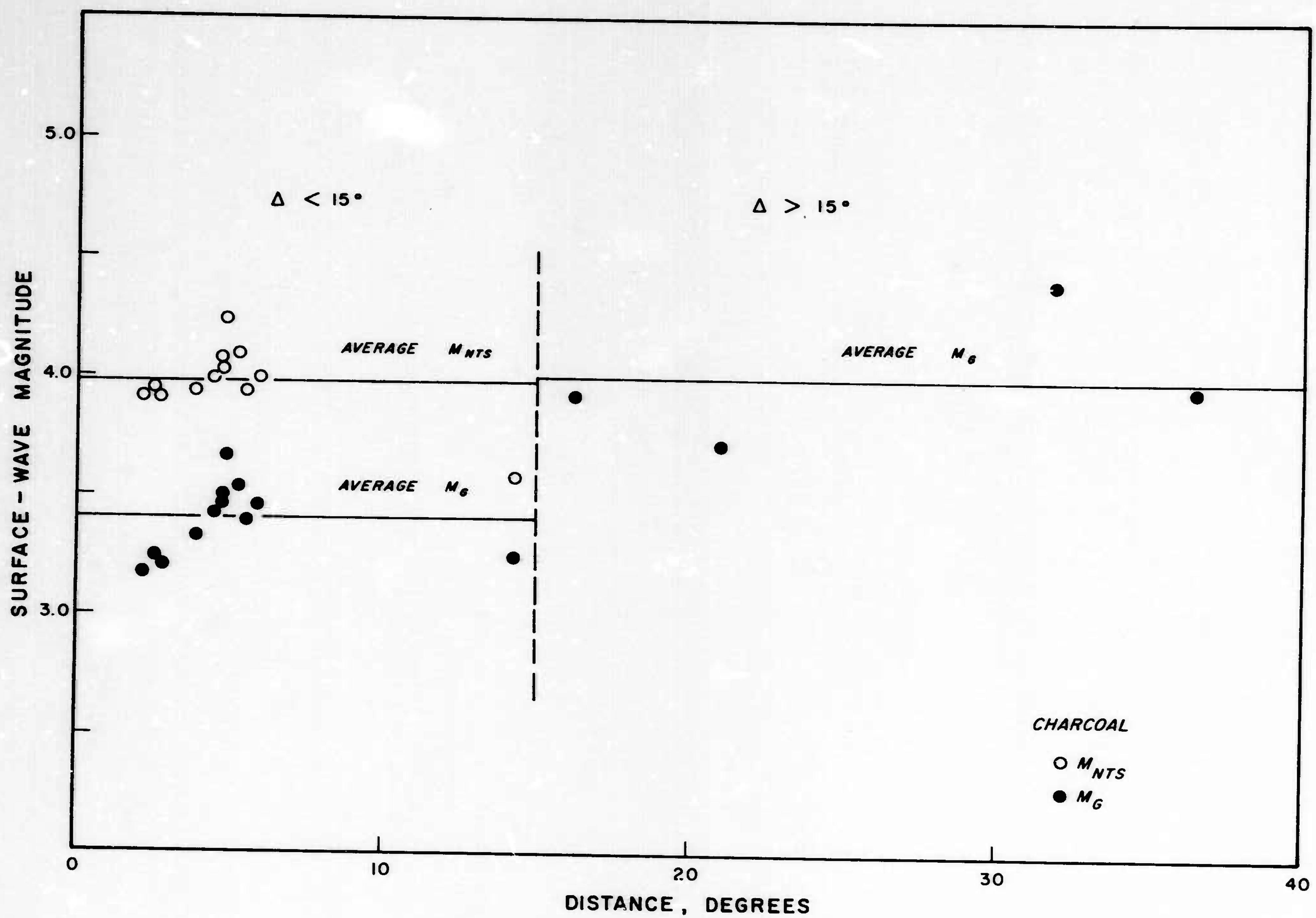

Figure 8. CHARCOAL - M_G and M_{NTS}

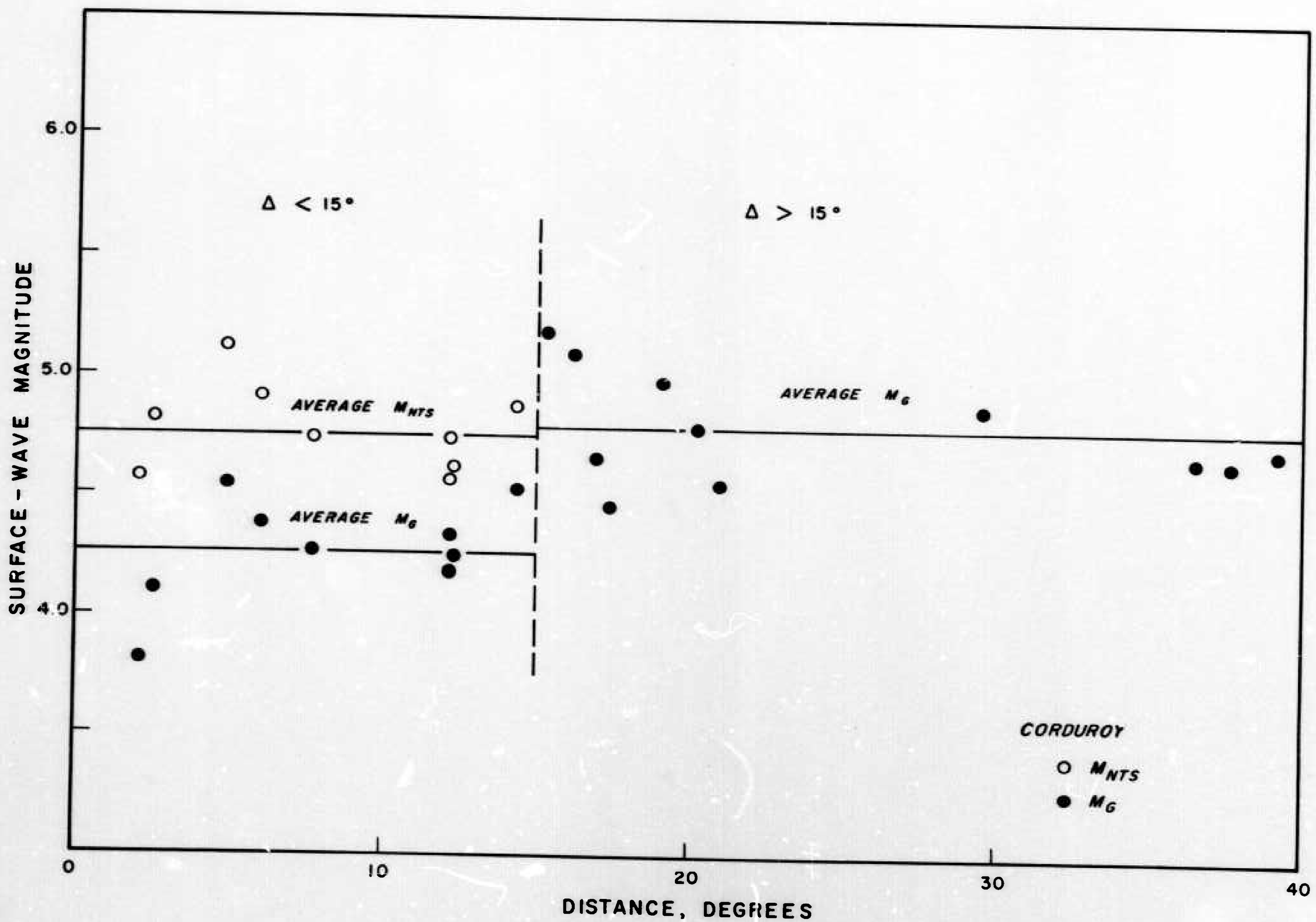

Figure 9. CORDUROY - M_G and M_{NTS}

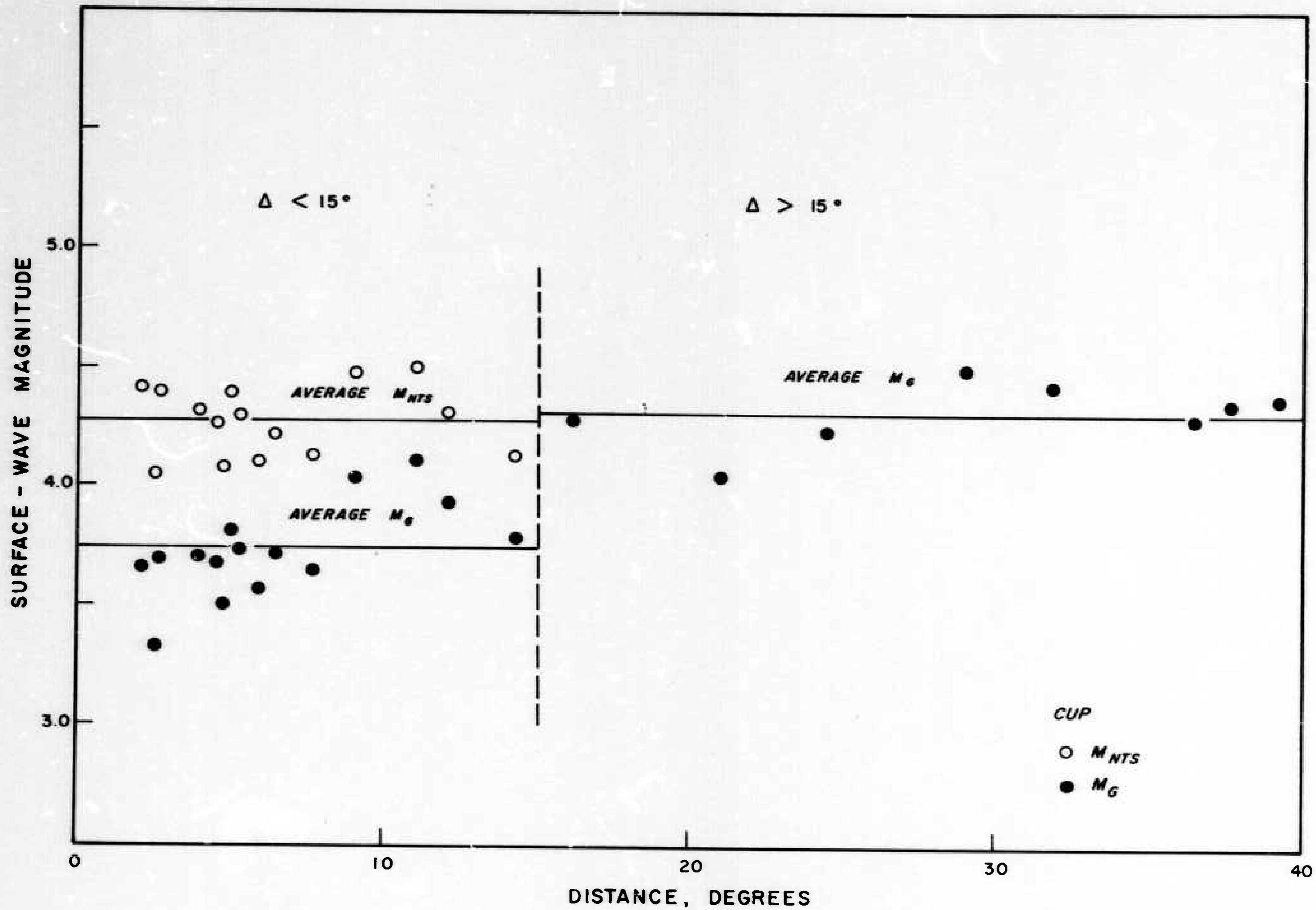

Figure 10. CUP - M_G and M_{NTS}

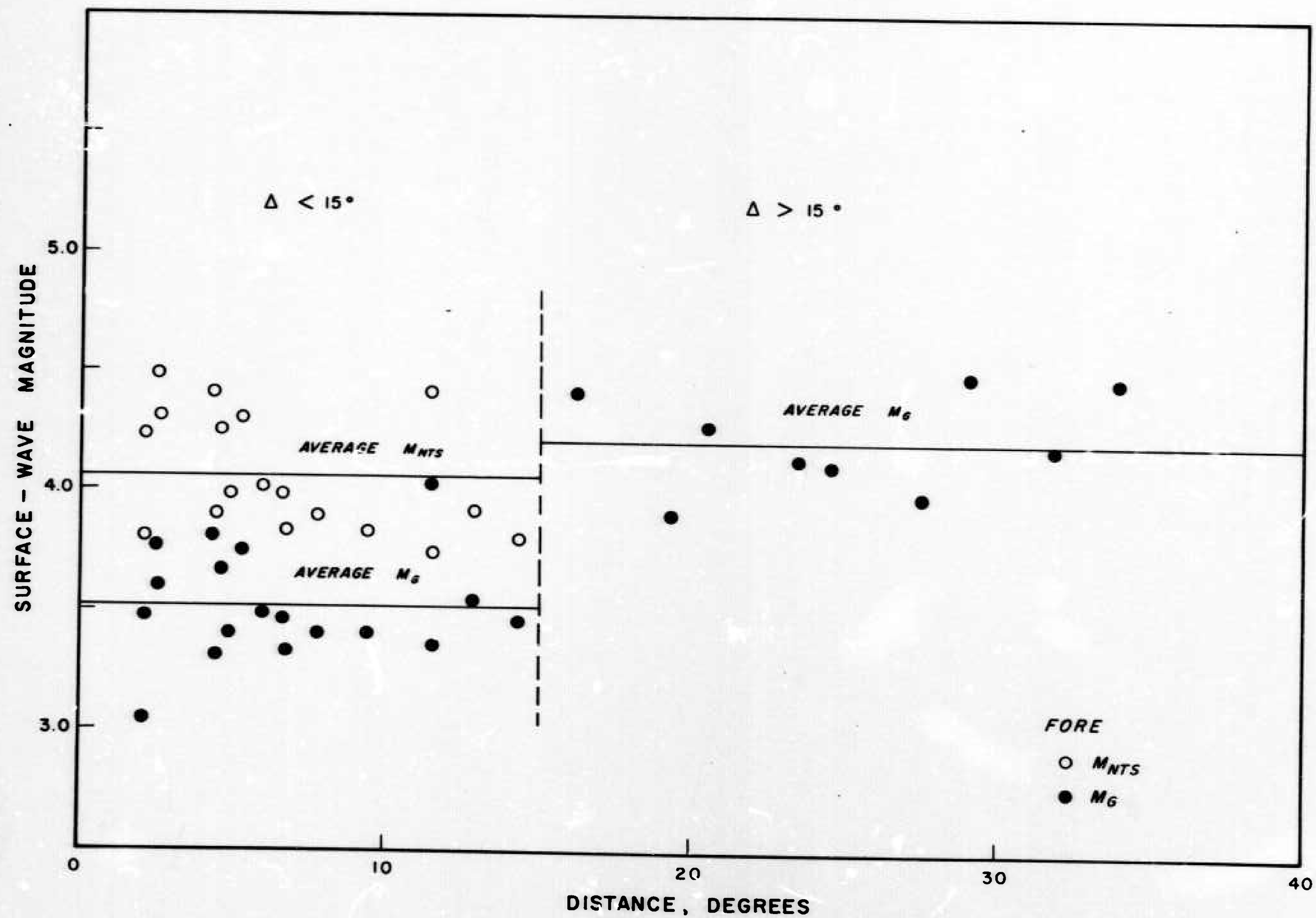

Figure 11. FORE - M_G and M_{NTS}

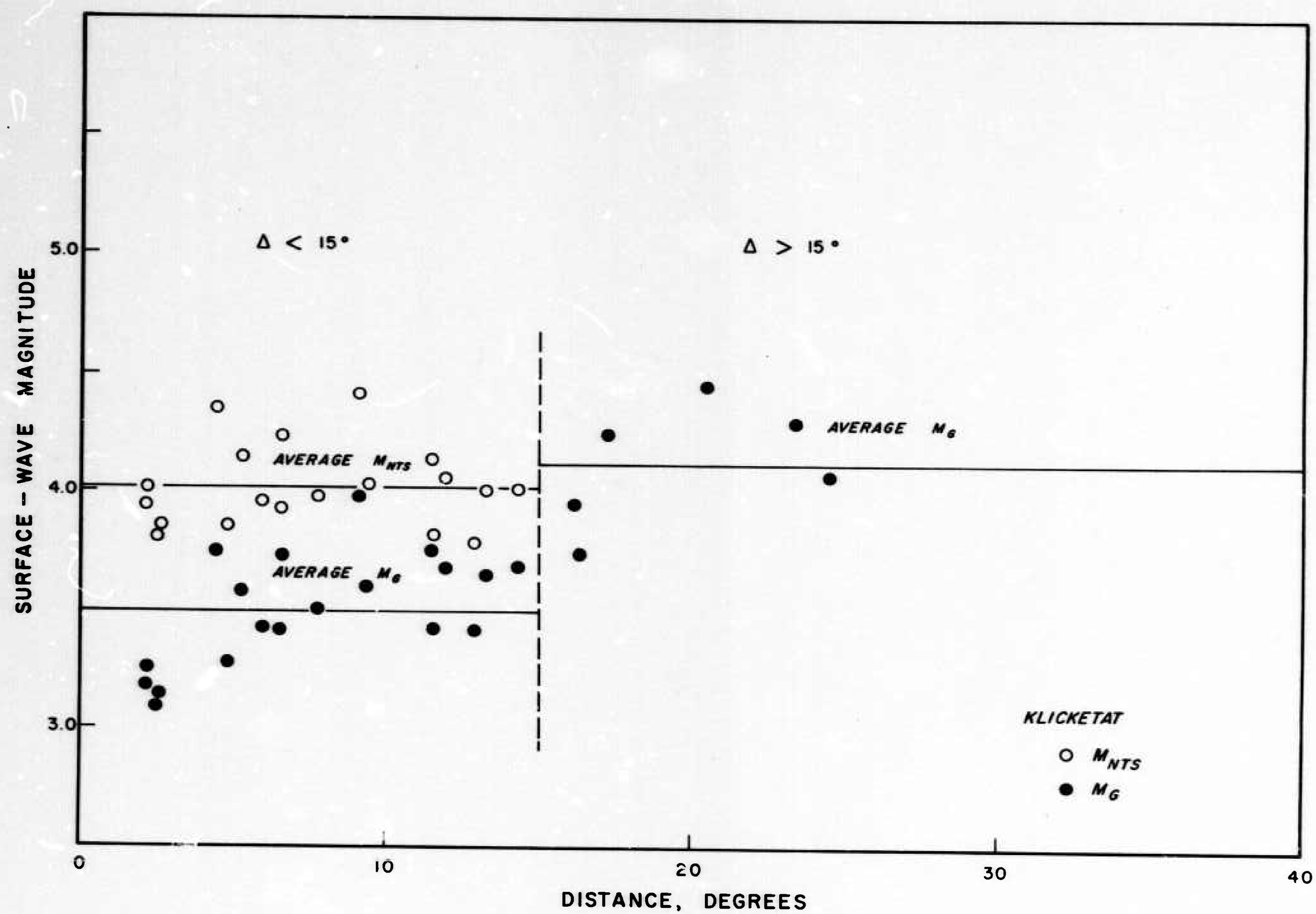

Figure 12. KLICKETAT - M_G and M_{NTS}

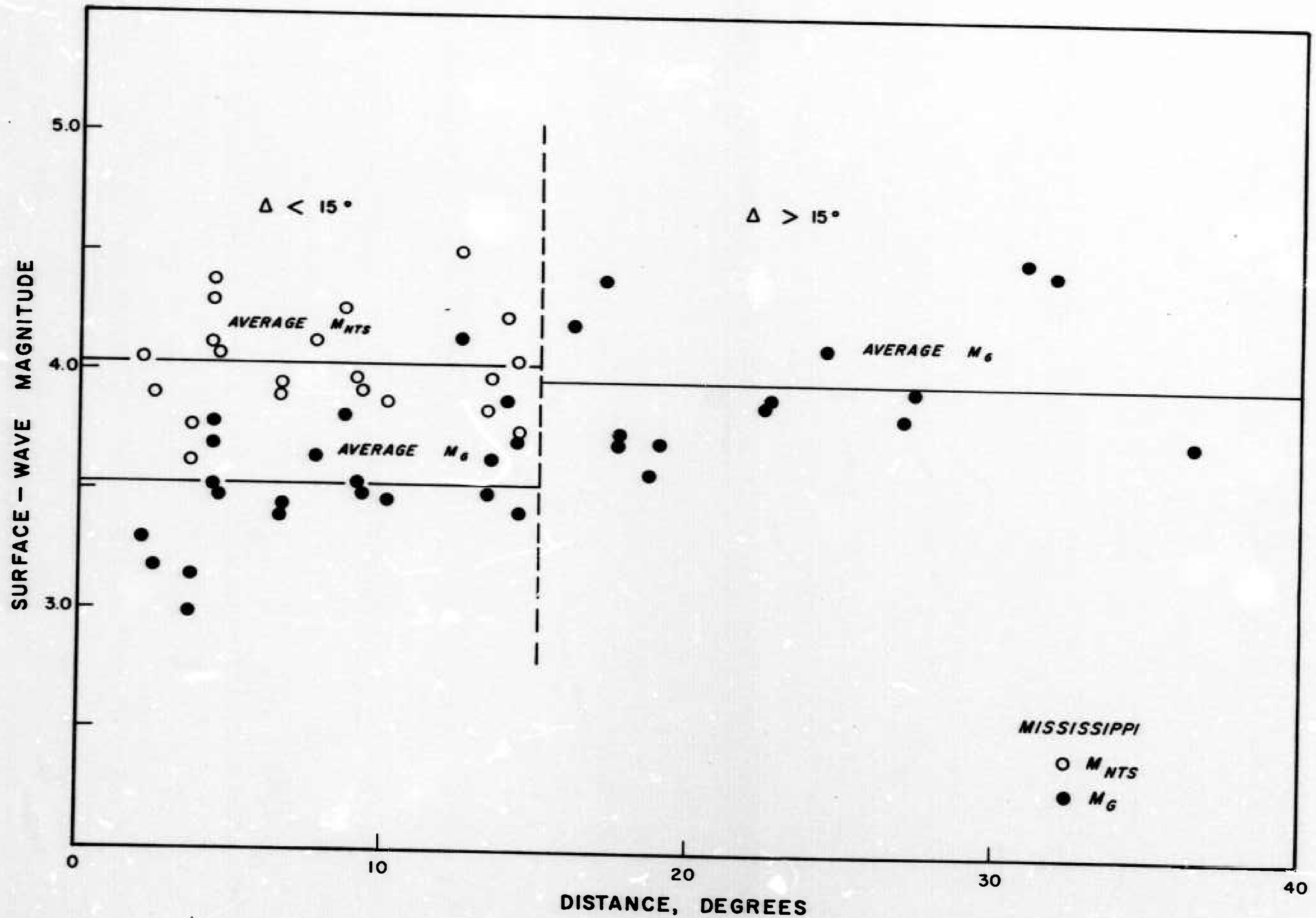

Figure 13. MISSISSIPPI - M_G and M_{NTS}

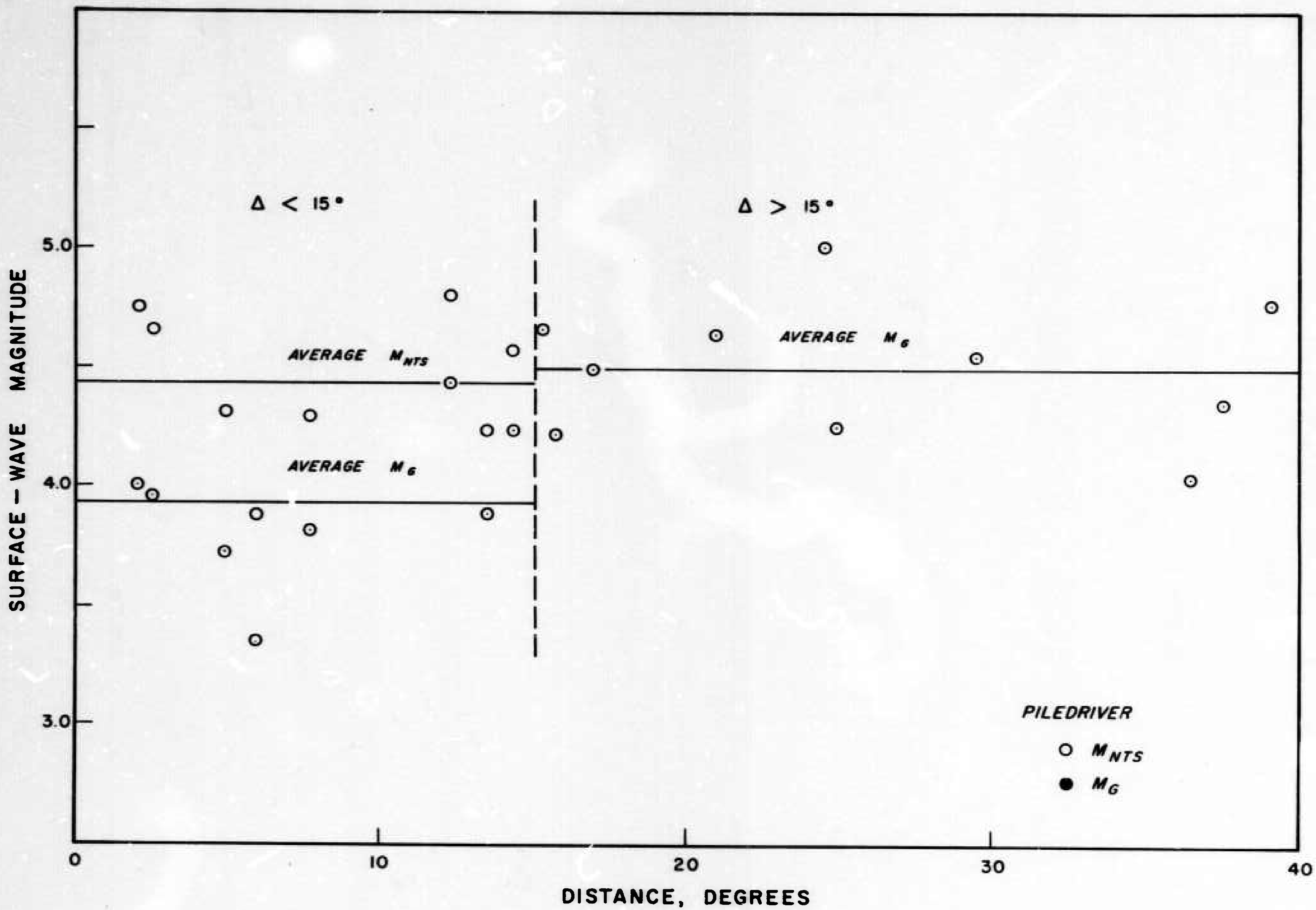

Figure 14. PILEDRIVER - M_G and M_{NTS}

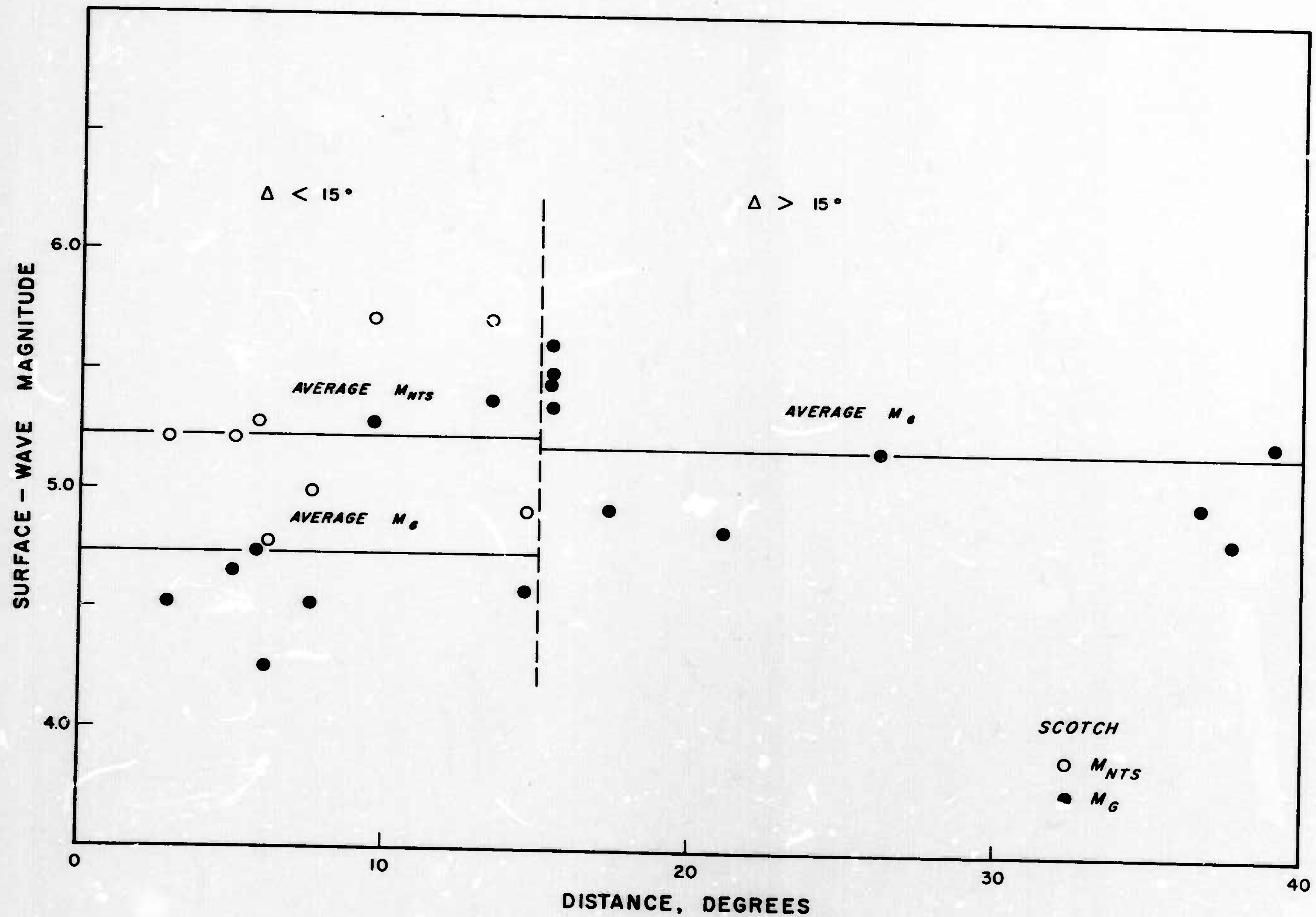

Figure 15. SCOTCH - M_G and M_{NTS}

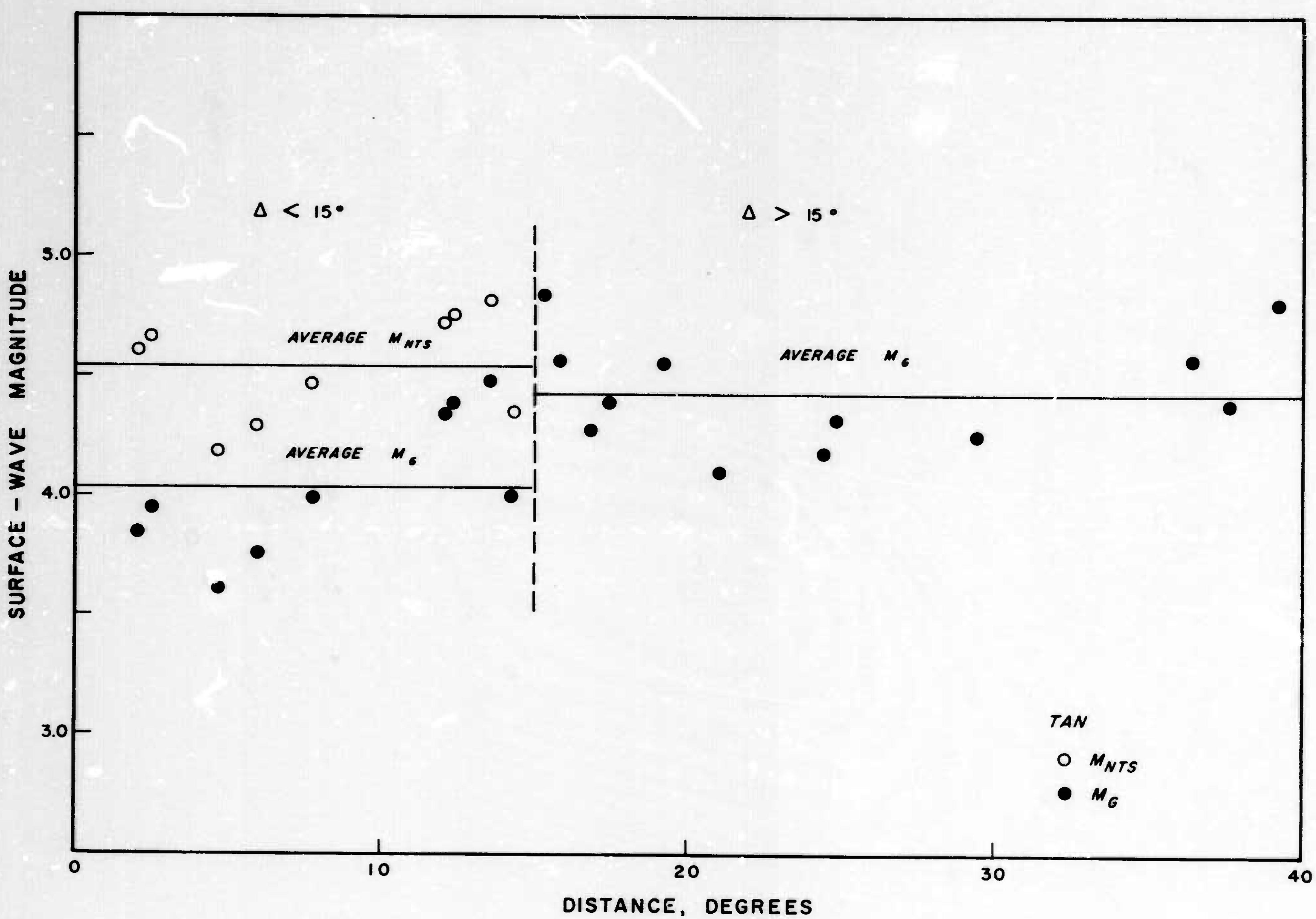

Figure 16. TAN - M_G and M_{NTS}

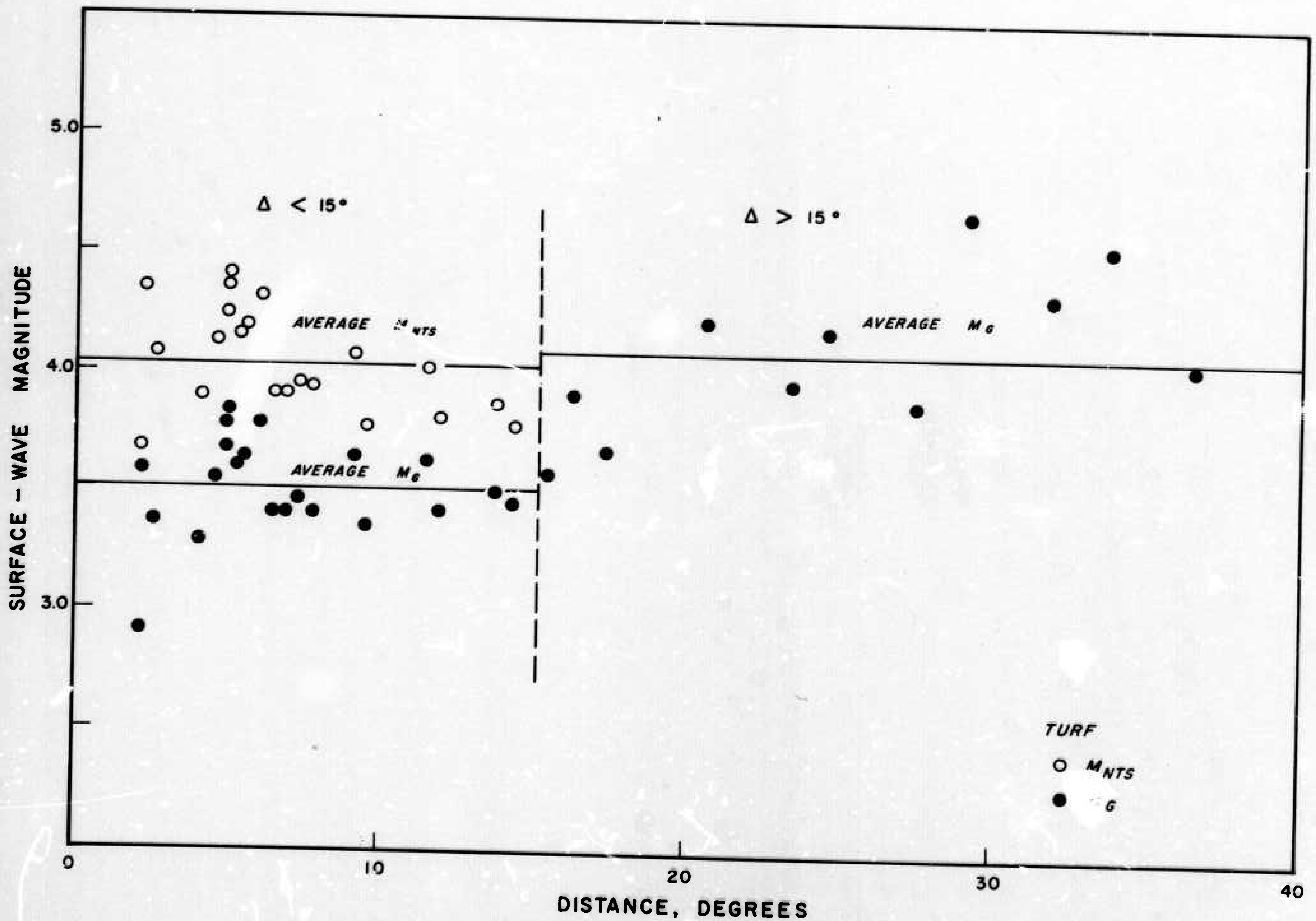

Figure 17. TURF - M_G and M_{NTS}

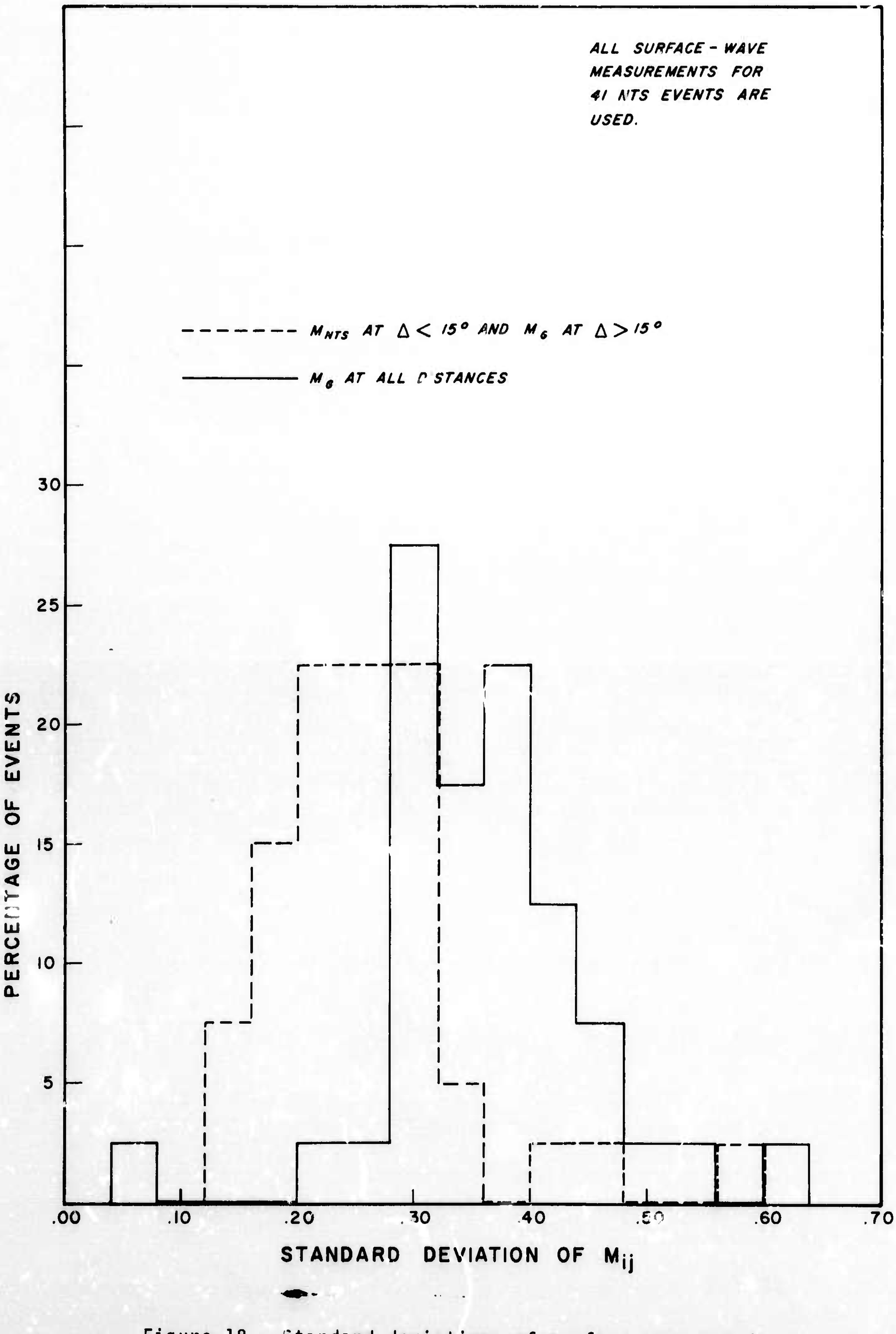

Figure 18. Standard deviations of surface-wave magnitude using NTS and Gutenberg "B" factors for 41 events.

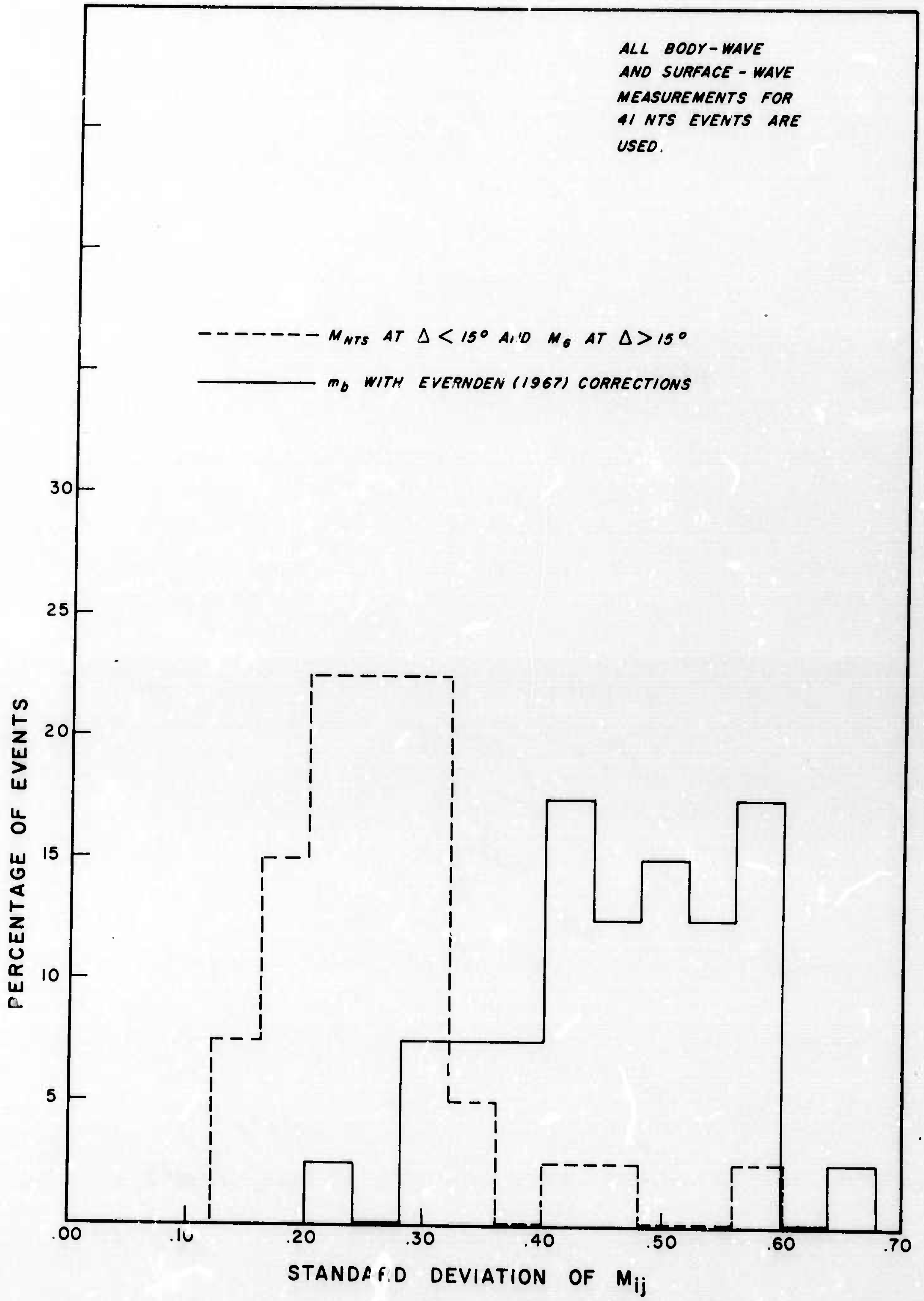

Figure 19. Standard deviations of body-wave magnitudes using Evernden's "B" factor and of surface-wave magnitudes using NTS "B" factor for 41 events.

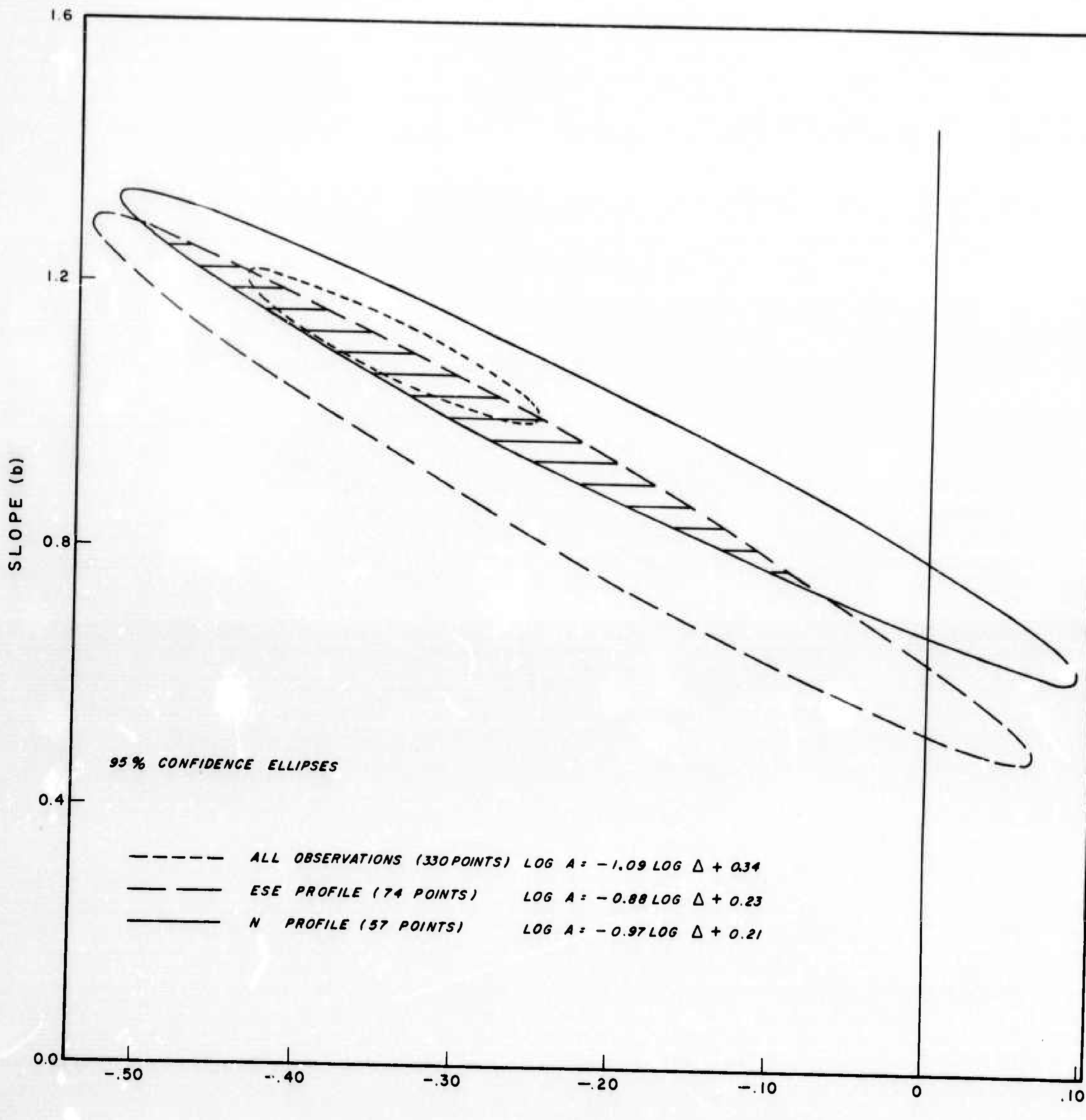

Figure 20. Least-squares solutions for "B" factor for N and ESE profiles - 95% confidence ellipses.

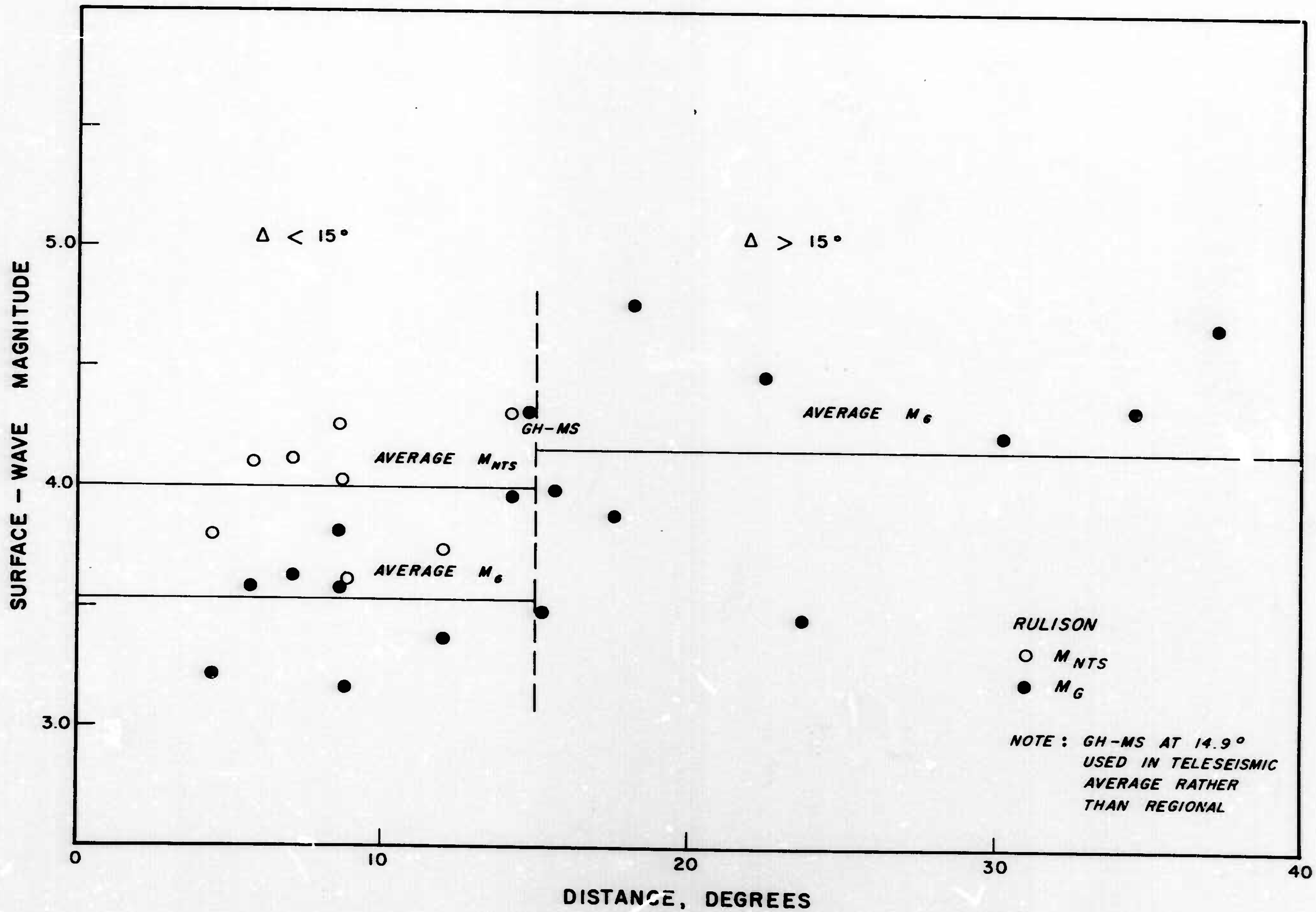

Figure 21. RULISON (Rifle, Colorado) - M_G and M_{NTS}

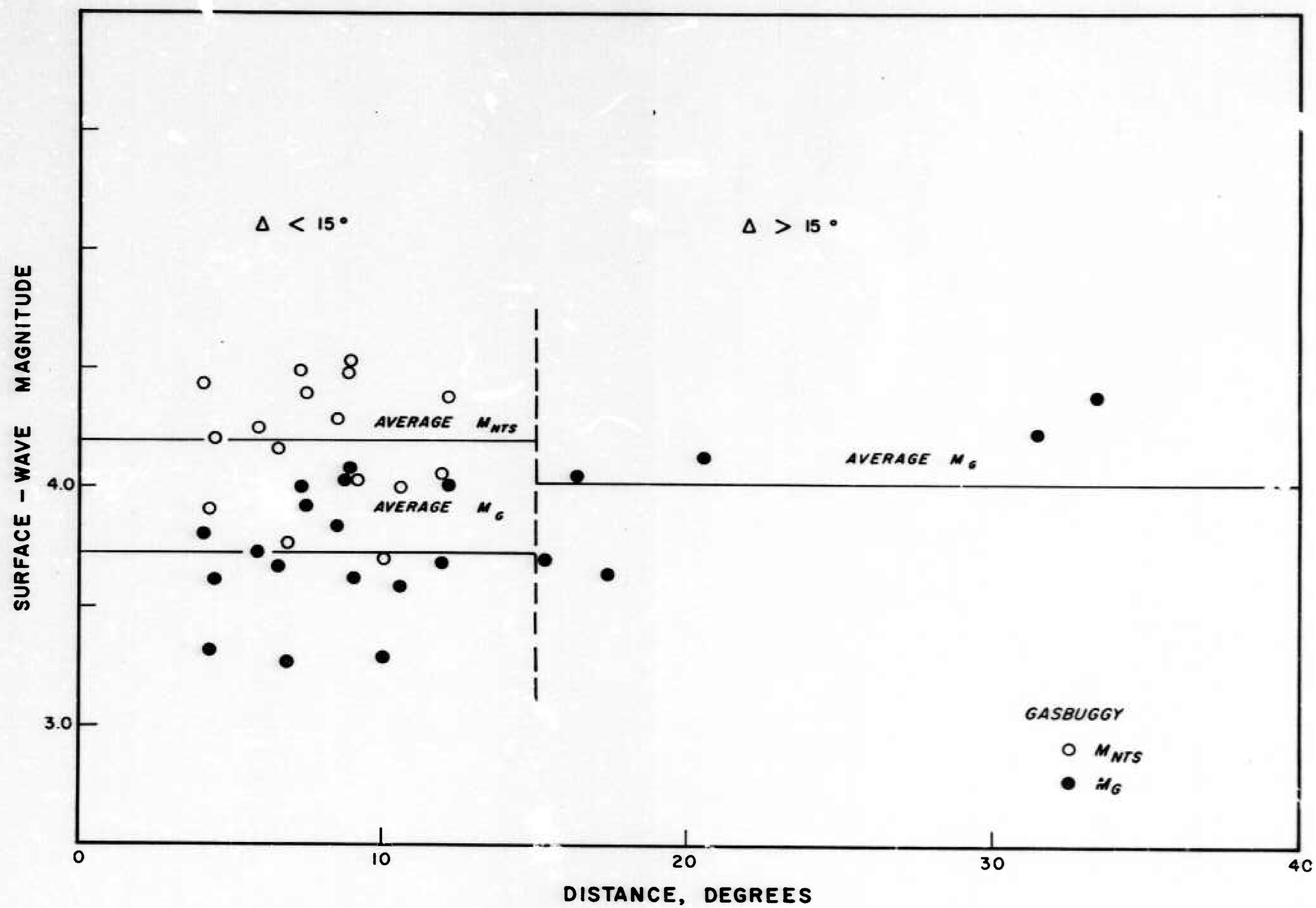

Figure 22. GASBUGGY (Farmington, New Mexico) - M_G and M_{NTS}

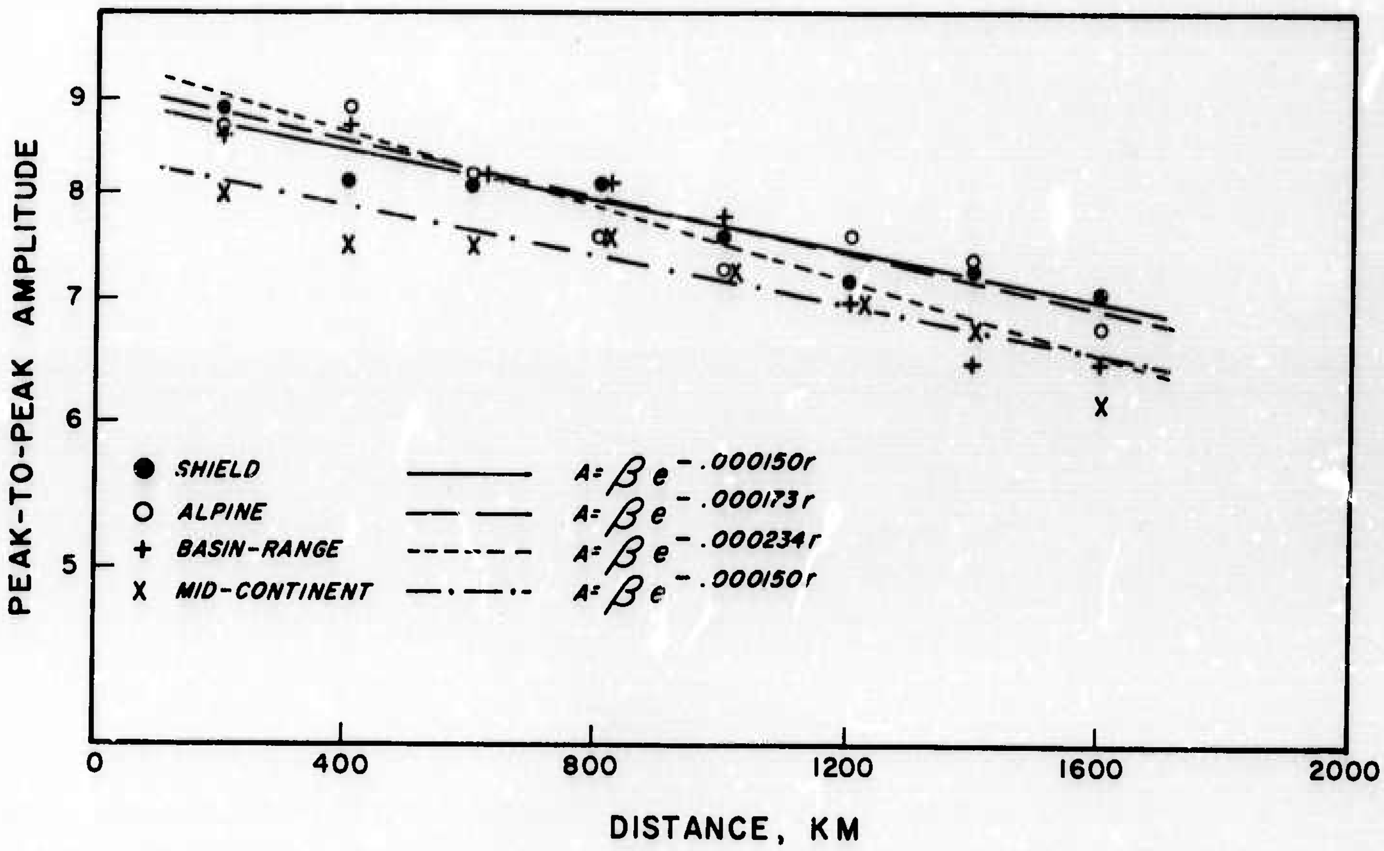

Figure 23. Effect of dispersion only on Rayleigh-wave maximum peak-to-peak amplitude.

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13 ABSTRACT

For epicentral distances less than 15° in the Western United States, a new correction factor is proposed for use in the common Gutenberg formulation for surface-wave magnitude. The data on which this is based are 684 Rayleigh-wave amplitudes from Nevada Test Site explosions measured visually on the records of LRSM mobile stations and VELA observatories. The need for the variable T (period) in the magnitude calculation is discounted on empirical evidence. Magnitudes at distances less than 15° when recomputed using the new correction factor are in excellent agreement with teleseismic magnitudes and show less scatter among themselves than previously. An estimate of the effective Q_R in the crust from the data is about 130. Amplitude losses should reflect other causes than anelasticity, and this value is undoubtedly much lower than the real Q_R.

14. KEY WORDS

Surface-wave amplitude
Surface-wave magnitude
Dispersion
Western United States

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